Part V

Integration, Installation, and Commissioning

Contents

Chapter 13

Integration, Installation, and Commissioning

13.1 Introduction

The purpose of this task is to coordinate the installation, integration and commissioning of the various detector components and the mechanical and electrical systems that comprise the BTeV spectrometer.

The BTeV detector is different from the two "central detectors", CDF and D0, currently operating in the B0 and D0 Interaction regions. CDF and D0 are hermetic detectors with a nested barrel geometry in which each barrel layer occupies a cylindrical annulus that is supported off of an adjacent radial layer. Large "endcaps" fill the upstream and downstream end of the barrel and make its contents somewhat inaccessible. In contrast, BTeV has an open, linear geometry in which each detector occupies its own space along the beamline,in Z, and is self-supporting. The installation, integration, and maintenance of a detector with this geometry is less demanding than for a hermetic, central region detector. It also permits a piecewise installation strategy. However, even with these advantages, the installation and integration of the BTeV detector in the small C0 enclosure will be a challenging task that will require careful planning and coordination.

Two things complicate the installation of the BTeV spectrometer. First, the C0 collision hall does not have a large crane; hence all components must be rolled into the hall. Second, the installation must not interfere with CDF and D0 data taking during Run II. The installation will need to occur during scheduled down days, upgrade shutdowns, and occasional repair periods of the Tevatron accelerator.

The integration of the various detector components must accommodate two important considerations. First, the physics requirement of a very low mass detector must be met. Second, the integration plan must help minimize the installation time needed in the C0 collision hall as noted above.

The commissioning of the BTeV spectrometer will also be influenced by the installation and integration requirements. First, commissioning procedures for the various detectors must be designed to allow as much commissioning as possible before installation in the C0 hall. Second, the capability for remote commissioning after installation must be incorporated in the design.

Considerations which have gone into determining these requirements include:

- The physics goals of the experiment
- The physical characteristics of both the events of interest and background events
- The physical characteristics of the C0 detector and assembly halls
- The lack of a crane and the limited access to the C0 collision hall
- The use of existing components and systems at Fermilab
- The ES&H issues

The current design of the BTeV detector includes one spectrometer arm along the forward antiproton rapidity direction with a large vertex dipole magnet at the interaction point in C0 and four large iron toroidal magnets, two at either end of the hall. It would be very difficult to install the large, heavy elements - the Vertex Magnet and the toroids - after other components are already in the hall. Therefore, these items will be installed first.A system of overhead tracks or suspension systems will then be installed to support the various detector units after they are rolled into position.

In this chapter, we describe the scope of the installation task and the common infrastructure of services that will be available in C0 and the associated counting room that will support the installation and operation of BTeV. For each detector, we discuss the "boundaries" between the construction task on the one hand and the installation, integration, and commissioning task on the other hand.In particular, we explain how costs and tasks are divided up for each detector. We then explain how each detector will be installed and integrated with the data acquisition system, trigger, slow control system. Finally, we describe the commissioning activities that will demonstrate that the various systems are "beam ready" and will constitute successful completion of the BTeV detector construction.

13.2 Requirements

This section describes the high-level requirements for the installation, integration, and commissioning of the BTeV spectrometer that are necessary for BTeV to achieve its physics goals. The primary goal of the installation coordination is to take maximal advantage of Tevatron down periods in order to install the complete BTeV detector in the C0 collision hall. The primary goal of the integration task is to minimize the interferences between the various detector components while simultaneously minimizing the amount of material in the aperture of the spectrometer. The primary goal of the commissioning coordination is to ensure that the spectrometer can be completely commissioned in a minimal amount of time.

13.2.1 Installation Requirements

The spectrometer consists of four major mechanical elements:

- the vertex magnet;
- the north and south muon toroid assemblies; and
- the beampipes that carry the Tevatron beams through the spectrometer.

There are also six major detector systems that must be installed in the spectrometer:

- the silicon pixel detector;
- the forward silicon tracking detectors;
- the forward straw tube chambers;
- the ring-imaging Cerenkov detector;
- the electromagnetic calorimeter; and
- the muon chambers.

All larger sub-assemblies, to the extent possible, must be staged or assembled in the C0 assembly hall and then, in a time efficient, coordinated way, rolled into the C0 collision hall and assembled into the BTeV spectrometer. They must then be surveyed and adjusted into precise position with respect to the Tevatron. Significant time for cable installation, electrical hookup, mechanical support, and gas interconnections must also be scheduled once the detectors are in the collision hall.

13.2.1.1 Requirement 2.1-1: Spectrometer assemblies

All spectrometer components must be assembled into sub-assemblies that can be efficiently rolled into the collision hall.

13.2.1.2 Requirement 2.1-2: Detector suspension systems

The detector elements in the spectrometer must have suspension systems that allow for quick insertion and removal from the spectrometer.

13.2.1.3 Requirement 2.1-3: Installation coordination

A detailed timeline must be developed for the assembly and staging of the spectrometer components in the C0 assembly hall and for the efficient installation of the components in the C0 collision hall as Tevatron down time permits.

13.2.1.4 Requirement 2.1-4: Gas systems

A detailed plan must be developed for the efficient and safe installation of the gas manifolds and gas system monitoring needed by the various detectors in the C0 collision hall.

13.2.1.5 Requirement 2.1-5 Electrical connection

A detailed plan for the installation of all cables and for connecting the electrical systems must be developed. An especially important aspect of this requirement is the development of an effective strategy and enforcement plan for the electrical isolation and ground connections of all electrical and electronic components in the C0 collision hall.

13.2.1.6 Requirement 2.1-6: Spectrometer Survey

All spectrometer components must be designed with survey fiducials that maximize the amount of internal survey alignment that can be done while in the assembly hall and which minimize the time needed for final alignment or realignment in the C0 collision hall.

13.2.2 Integration requirements

The performance of BTeV spectrometer depends on minimizing the amount of material in the spectrometer aperture and also in ensuring that the various detector subsystems fit together in a way that facilitates their installation and maintenance.

13.2.2.1 Requirement 2.2-1: Material Budget

The suspension systems for the various detector elements must be designed to minimize the number of radiation lengths of material in the spectrometer aperture.

13.2.2.2 Requirement 2.2-2: Detector Mounts

The suspension systems of the various detector elements must be designed to allow efficient installation and maintenance.

13.2.2.3 Requirement 2.2-3: Detector Electronics

The various electronic assemblies needed for the spectrometer must be designed to allow easy access and maintenance of the detectors and their associated electronics with a minimum of interference between different systems.

13.2.2.4 Requirement 2.2-4: Spectrometer Cables

A cable routing plan must be developed for the complete spectrometer. The cables needed for spectrometer readout and monitoring must be designed to allow quick installation and maintenance. They must be kept out of the active aperture of the spectrometer as much as possible. They must be designed to operate (consistent with design goals) over the expected lifetime of the experiment.

13.2.3 Commissioning Requirements

The BTeV spectrometer components must be tested, calibrated and commissioned before data on B-meson decays can be productively acquired. The commissioning must be accomplished with a minimum of access time into the C0 collision hall.

13.2.3.1 Requirement 2.3-1: Component Testing

To the greatest extent possible all spectrometer components should be tested before they are installed in the C0 collision hall. All testing that must be done after installation in the C0 detector hall should be designed to facilitate remote testing to the greatest extent possible.

13.2.3.2 Requirement 2.3-2: Component Calibration

The calibration of spectrometer systems should be designed to allow remote calibration to the greatest extent possible. All calibrations should be integrated into the BTeV DAQ and software systems as much as possible and should follow BTeV software standards.

13.2.3.3 Requirement 2.3-3: Spectrometer Commissioning

The various components of the BTeV spectrometer will be declared commissioned when they have met the requirements stated in their respective requirements documents, and when all as-built construction, operation, and maintenance documents have been assembled. The overall BTeV spectrometer will be declared commissioned when all as-built, operation and safety documentation has been assembled and when the complete spectrometer is installed and commissioned in the C0 collision hall.

13.2.4 Fault Tolerance

Since installation coordination is critical in achieving the goals of this task, the installation plan must be designed to allow some flexibility with respect to the arrival time of components in the C0 assembly hall preparatory to installation.

13.2.4.1 Requirement 2.4-1: Component availability

The installation schedule must allow for some variability in the arrival time of spectrometer components at the C0 assembly hall.

13.2.4.2 Requirement 2.4-2: Component testing and commissioning

The installation schedule must allow adequate time and space in the C0 assembly hall to carry out as much testing and commissioning as possible before installation.

13.2.4.3 Requirement 2.4-3: Component survey

The installation schedule must allow for as much internal survey as possible before the installation of components in the C0 collision.

13.2.5 Integration and Surveying

Installation, integration and surveying tasks are necessarily intertwined in the BTeV spectrometer. Care must be taken to allow adequate time at each step of the installation for necessary integration and survey tasks to be completed.

13.2.5.1 Requirement 2.5-1: Installation Survey

A coordinate reference system for the C0 collision hall must be delineated and must be maintainable over the life of the experiment. This coordinate system should be anchored on the walls of the C0 collision hall and must include the Vertex Magnet as a fundamental element in the primary coordinate system and survey. Provision must be made for easy accessibility to this primary survey reference system as individual components and systems are installed. The survey must be reproducible throughout the course of the experiment.

13.2.5.2 Requirement 2.5-2: Relative alignment

It is anticipated that small motions of the precision tracking detectors will occur daily. A plan for recording the relative positions of all detectors in real time, as observed by tracking analysis software, must be integrated into the BTeV DAQ and online software.

13.2.5.3 Requirement 2.5-3: Realignment

It is can be anticipated that the C0 collision hall floor, and hence the spectrometer components, will move with respect to the primary Tevatron beam over time. Thus provision must be made for subsequent small (of order ± 5 mm) adjustments of all component and system positions after initial installation.

13.2.6 Commissioning, Control and Monitoring

In order to effectively and completely commission the spectrometer, each component or system installed must have provisions for control and monitoring. The control and monitoring systems must be assembled and tested before installation.

13.2.6.1 Requirement 2.6-1: Controls

Commissioning of all components and systems must include commissioning all DAQ electronics and DC voltage controls associated with those systems.

13.2.6.2 Requirement 2.6-2: Monitoring

Commissioning of all components and systems must include commissioning of all monitoring, equipment protection, and safety systems associated with those systems. Some BTeV detector and component systems will include alarms and limits on their excitation and status that will be monitored via an interface to the ACNET control system; ACNET interface testing must be included in commissioning these systems.

13.2.6.3 Requirement 2.6-3: Environmental control

Commissioning of the complete BTeV spectrometer must include the commissioning of all HVAC and other environmental controls needed by the detectors in the C0 collision hall.

13.2.7 BTeV Spectrometer Mechanical, Electrical and Vacuum Standards

There will be many mechanical, electronic, electrical and vacuum subsystems in the BTeV spectrometer. They must be installed and commissioned in compliance with all applicable Fermilab Standards as well as any additional standards adopted by the BTeV group.

13.2.7.1 Requirement 3.1-1: Mechanical Standards

All mechanical systems in the BTeV spectrometer will be installed and commissioned in compliance with all applicable Fermilab and BTeV group Mechanical Standards.

13.2.7.2 Requirement 3.1-2: Electrical and Electronics Standards

All electrical and electronic systems in the BTeV spectrometer will be installed and commissioned in compliance with all applicable Fermilab and BTeV group Electrical Standards.

13.2.7.3 Requirement 3.1-3: Vacuum Standards

All vacuum systems will be installed in accordance with Fermilab and BTeV Group Vacuum Standards.

13.2.8 Software Requirements

There will be much software needed for commissioning, testing, control, and monitoring of the BTeV spectrometer components and systems.

13.2.8.1 Requirement 4.1-1: Software Standards

Software Development will conform to the BTeV Software Standards.

13.2.9 ES&H Requirements

Many BTeV components and systems will have stored energy (electrical, magnetic and vacuum) during testing and commissioning that could constitute a safety hazard.

13.2.9.1 Requirement 5.1-1: Mechanical safety

All mechanical aspects of the BTeV spectrometer will conform to the Fermilab ES&H manual on electrical safety.

13.2.9.2 Requirement 5.1-2: Electrical safety

All electrical aspects of the BTeV spectrometer will conform to the Fermilab ES&H manual on electrical safety.

13.2.9.3 Requirement 5.1-3: Vacuum Safety

All vacuum systems in the BTeV spectrometer will conform to the Fermilab ES&H manual on Vacuum Systems.

13.3 Boundaries between Detector Construction Tasks and Installation, Integration, and Commissioning

13.4 Physical Infrastructure

The basic support systems will be in place in C0 well before detector component installation begins. This building infrastructure includes

- The C0 Assembly Area: This is a building, shown in Fig. 13.1, adjacent to the C0 Collision Hall that can be used to assemble components of the detector. The Assembly Hall has a 30 ton crane to assist in assembling large devices. At ground level, there is a loading dock for moving large components into the Assembly Hall. The crane coverage extends over the loading dock so that the crane can be used to lower large objects to the Assembly Hall floor. After assembly, components can then be rolled or otherwise transported into the Collision Hall. Access to the Collision Hall from the Assembly Hall for large objects is accomplished by removing the "shielding wall" that separates the Assembly Hall from the Collision Hall. The Collision Hall also has an alcove that houses the power supplies that operate the Vertex Magnet, Compensating Dipoles, and Toroids that are part of the BTeV spectrometer and reside in the Collision Hall. These supplies can also be used to power the magnets for testing and field mapping while the magnets are in the Assembly Hall.

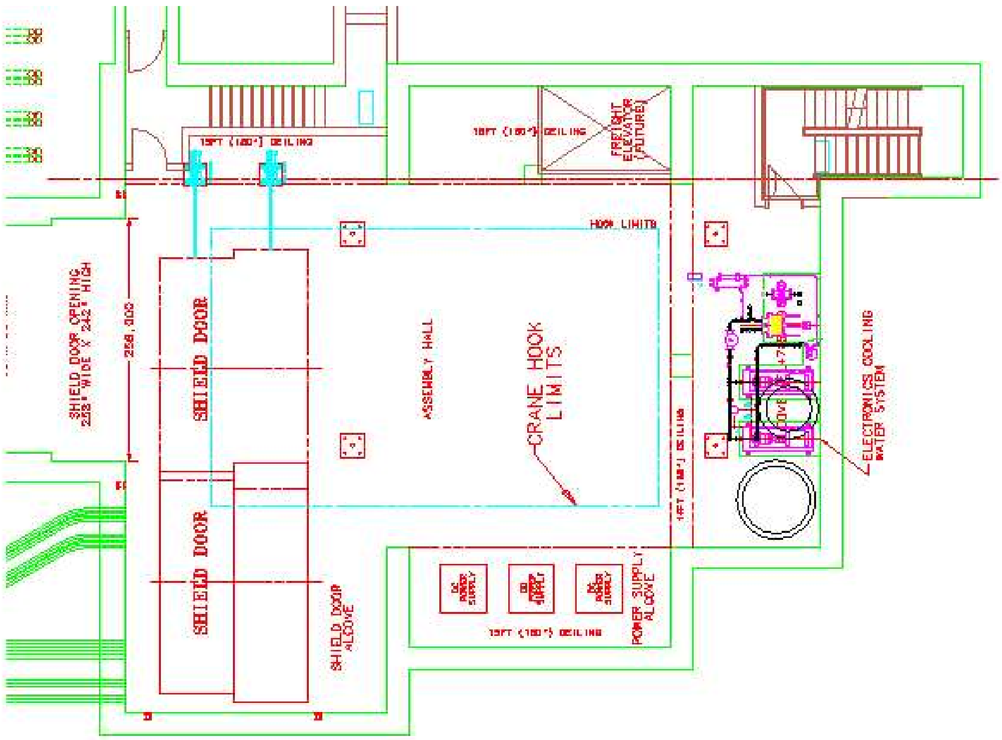

Figure 13.1: Layout of C0 Assembly Hall, showing crane coverage.

- The C0 Collision Hall: This enclosure, shown in Fig. 13.2, houses the BTeV spectrometer and is where the beams collide. The hall is 24 m long, 9 m wide,, and 6.75 m high. It has no crane. It has switchgear for the power for the spectrometer components, gas supplies for tracking chambers and the RICH, and water for cooling. The Hall is air-conditioned and the temperature is expected to be stable to XX degrees and uniform to YY degrees. There are support structures for all the components and relay racks and cable runs for the electronics. The Collision Hall has a network of survey references for alignment purposes.

- The C0 Counting Room: The C0 Counting Room is a three story building, shown in Fig. 13.3. The first floor contains ...

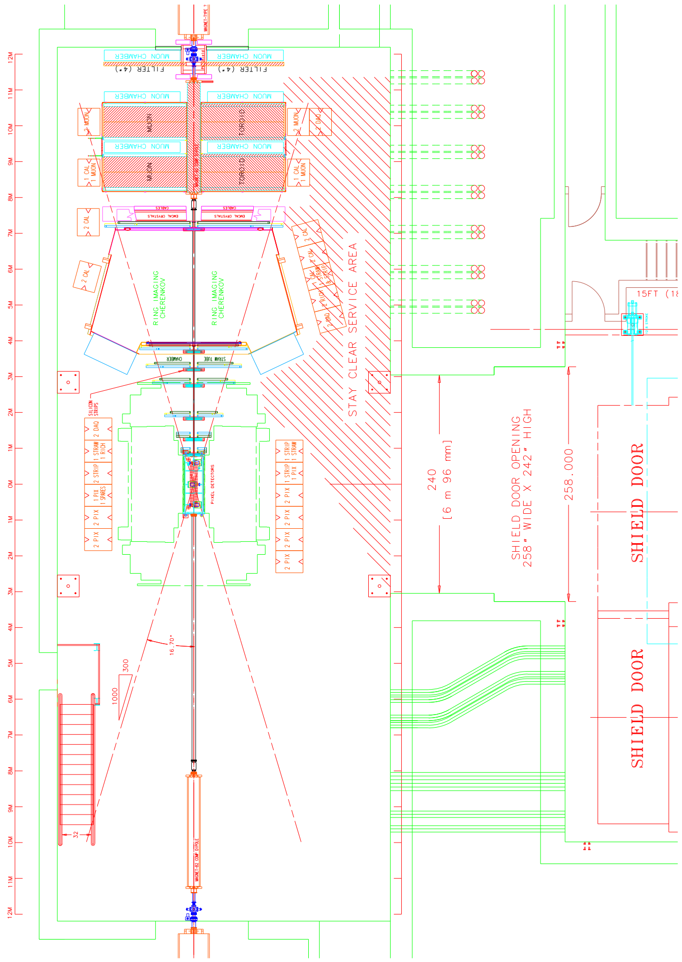

Figure 13.2: Layout of C0 Collision Hall

13.5 Electrical and Electronics Infrastructure

This section will give details regarding electrical and electronics infrastructure components and their proposed locations at C0. Where systems are common to various sub-detectors the overall system approach is discussed in this section of the TDR. Details that pertain to an individual sub-detector are in the discussion of that detector in Part-3. For example, high-voltage and low-voltage power is included in both places. The general common features and the utility nature of common power systems are here. The details of its use for each front-end detector are in that sub-detector's section.

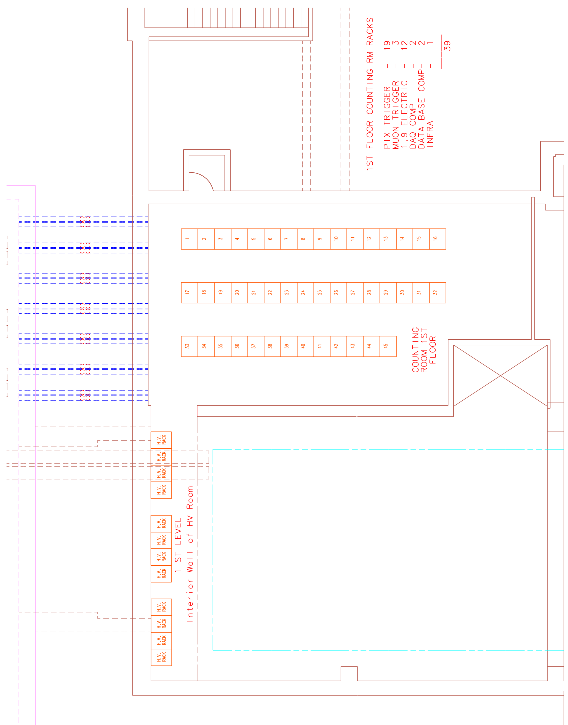

Figure 13.3: Layout of C0 Counting Rooms: First floor

The assumption made in this document is that the C0 building will have the basic utilities installed. AC power distribution panels will be in place throughout the building. The counting room will be completed with raised flooring, under floor air-conditioning, chilled water supply, lighting, etc. The facilities for placing the backup generator will be in place.

Electrical noise in experiments has been a major problem for sensitive analog electronics. It can come from a number of sources, poor grounds, ground loops, digital electronics, power supplies, etc. BTeV has attempted to mitigate the noise problem with attention to all these issues. Power supply location, filtering and grounding is based on our own work and discussions with other experiments. Another major source of noise has been that generated by the transmission of digital signals, both radiated and conducted. BTeV has, where possible, mandated the use of fiber optics to eliminate both of these noise sources.

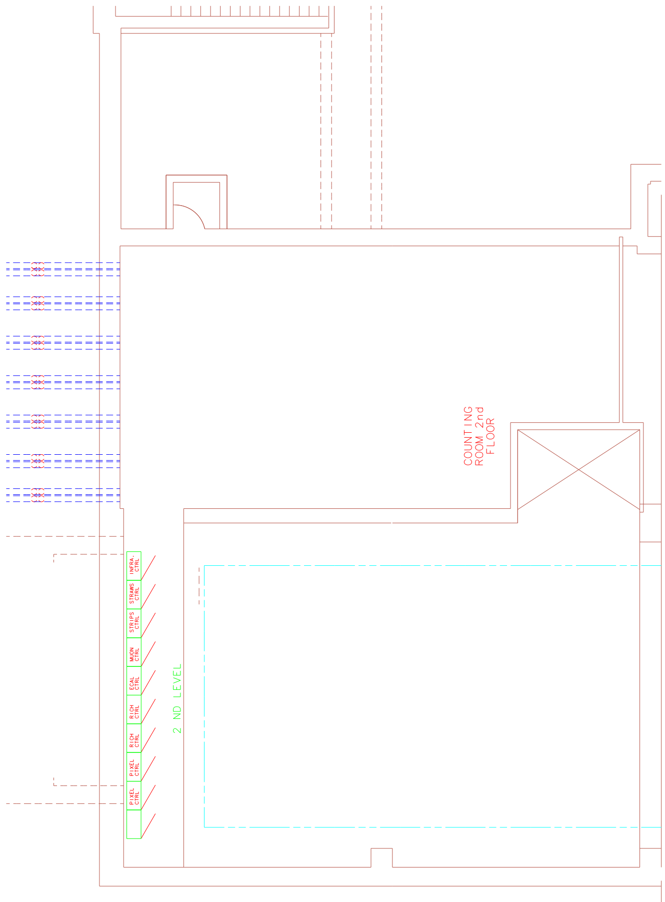

Figure 13.4: Layout of C0 Counting Rooms: Second floor.

This section will also briefly discuss an alternate DC power scheme using DC/DC converters. Although this is not part of the baseline, the technology is developing rapidly and will be considered for BTeV. Many power supply problems in grounding and isolation could be solved with this powering technique.

Radiation effects on power supplies have been addressed by placing most all of the sensitive high-voltage supplies behind the shielding wall. Only the RICH detector's 17kV and 20kV high-voltage supplies are in the Collision Hall. They are positioned such that the magnet can provide shielding from radiation damage. This has an effect on the cable plant but

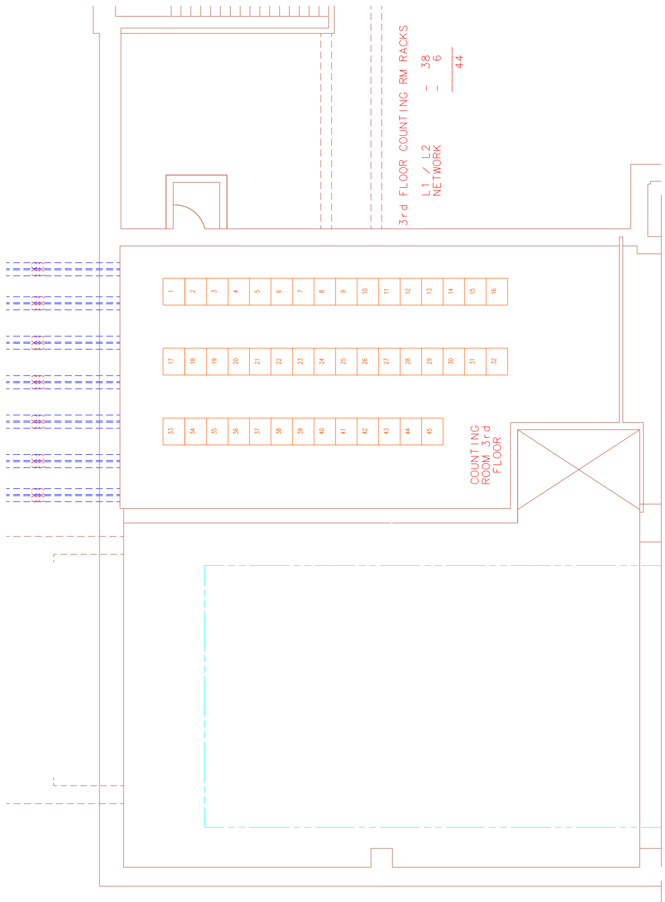

Figure 13.5: Layout of C0 Counting Rooms: Third floor.

eliminates problems that have been observed with the radiation tolerance of high-voltage supplies. An alternate scheme for the RICH, MAPMT (Multi-Anode PMTs) is under investigation. If this system is selected, the power supplies will be positioned in the first floor extension area.

BTeV has adopted a philosophy of standards as much as possible. This approach minimizes costs and makes maintenance easier. Personnel training on different systems are minimized. Spare parts inventory is reduced along with the corresponding costs. The standard relay racks, monitoring and powering of the electronics are in the subsequent chapters of this section.

Other issues are addressed in chapters on safety, long-term parts storage and safety grounding of the electronics. The general layout of the C0 collision hall, counting rooms, and annex areas are shown in drawings 8918.000-LE-407232 (1 sheet) and 8918.000-LE-407322 (2 sheets).

13.5.1 AC Power

The BTeV experiment will be served from two 1500KVA transformers located in the parking lot area adjacent to the C0 experiment hall.

13.5.1.1 Main AC Feed

Each transformer or substation will feed a DHP panel or "switch gear" located in the first floor 'panel room'. DHP-C0-1 is the switchgear that feeds the detector and related equipment except for the magnet power supplies. It also feeds the assembly hall and most of the office areas. DHP-C0-2 is the switchgear that feeds the cryo equipment, magnet power supplies, chillers, crane and other miscellaneous needs.

13.5.1.2 Backup AC Generator and Switchover Controls

There is one 250KW backup or "standby" diesel generator also located in the parking area. The output from the generator feeds via automatic transfer switch into DHP-C0-2 switchgear, which supplies power to "critical loads" in C0.

13.5.1.3 Distribution and Breaker Panels

208VAC three-phase distribution panels will be located in the Assembly Hall, the Collision Hall, and each Counting Room floor and in the main panel room. All 110VAC convenience outlets and 'office' power will be controlled from the panels in the main 'panel room'. Each of the other main areas shall have the distribution panel and breakers located within that area.

Main disconnects shall be located in the master panel room on the first floor. Remote trips for the Main Disconnects shall be located in the first floor control room.

13.5.1.4 Detector Subsystem Panels

Detector subsystem panels shall be located in the following areas:

- One panel for on-detector electronics shall be located within the collision hall itself.
- A second panel for other (not on-detector) collision hall electronics shall be located within the collision hall.

- One panel for detector electronics test and commissioning shall be located within the assembly hall.

- One panel shall be located within each counting room. A separate sub-panel driven from the counting room panel shall be provided in each counting room annex.

A 'crash button' remote trip shall be provided for each detector subsystem panel, located within 10 feet of the panel itself.

13.5.2 Detector DC Power Supplies

High-Voltage

All HV power supplies are located on a catwalk or "counting room extension" over access door outside the collision hall and cabled into the C0 hall. They will be routed over the top of the shielding door through a labyrinth channel. This removes the HV systems from the radiation area and greatly improves their reliability. The only high-voltage supplies that will be in the C0 hall are the 20 kV supplies for the RICH HPDs. These 20 kV supplies will be positioned and shielded to minimize the radiation.

Low-Voltage

The baseline design has AC to DC power supplies (conventional) located in the racks associated with each sub-detector. The power is then fed to each detector as required.

13.5.3 Water Supplies for Cooling Electronics

A chilled water supply is located in the C0 building for cooling electronics. The system is called the Electronics Cooling Water system to distinguish it from the Chilled Water System that will be used for the Building Air Conditioning and operates at a temperature of approximately 7 C. The Electronics Cooling Water system will be regulated to operate at 15 C and at least 5 C above the dew point of the hall. The system will circulate water with corrosion inhibitors. An ultraviolet sterilizer will be part of the system to prevent bacterial induced corrosion. Higher power racks in the counting room first level and collision hall will use air-water heat exchangers within the racks for cooling. The connection points for the racks will be along the walls or under the counting room floor.

13.5.4 Location of Building Stake(s) to Earth Ground

Each transformer will be staked to Earth Ground at the transformer to provide sufficient connection to earth. These stakes are in addition to the building grid, which is staked at one corner of the building.

13.5.5 BTeV Detector Grounding Scheme

Our thoughts about detector grounding have been guided by past experience at Fermilab, and particularly by the experience of D0. The D0 design philosophy is described in a paper by Marvin Johnson available at: http://www-ppd.fnal.gov/EEDOffice-w/Infrastructure_group/Grounding/Grounding_and_Shielding_Techniques.pdf This section presents the current state of thinking on the grounding issues facing BTeV. We believe that strict discipline will be required to guarantee that the full detector has a low noise environment. This is viewed as essential for rapid commissioning and smooth operation. Refer to Figure 13.6 for the grounding schematic.

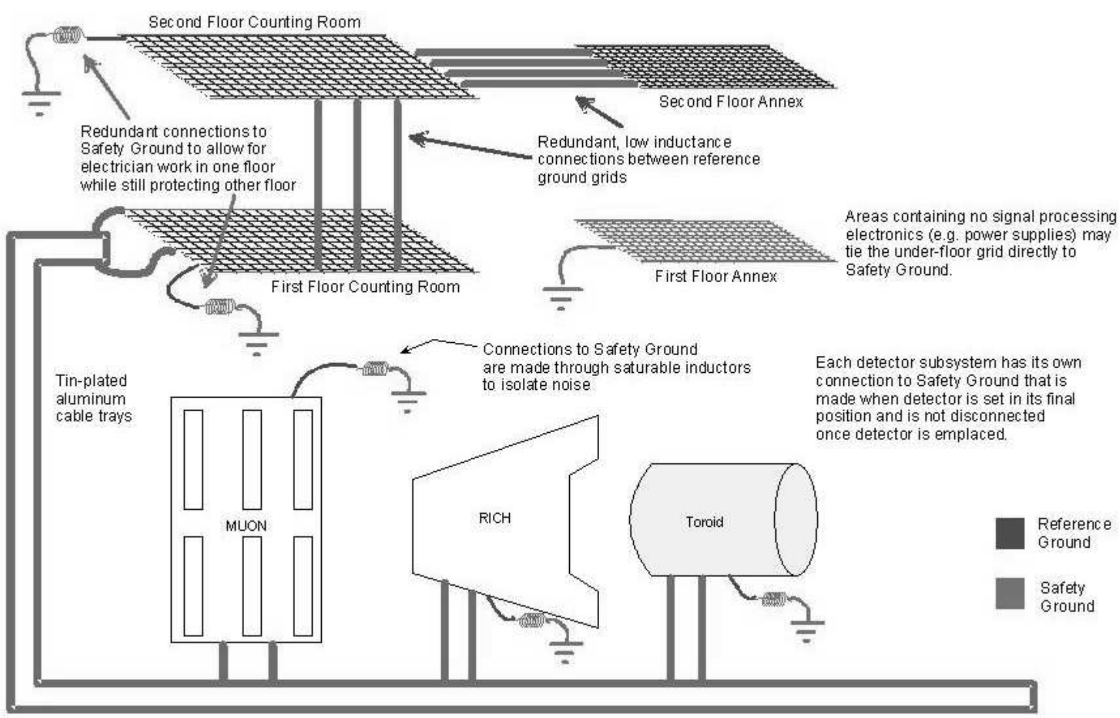

Figure 13.6: BTeV grounding scheme.

Distinction between Reference and Safety Ground

The term "ground" is commonly overused to the point where its exact meaning is lost. Many people erroneously use the term "ground" when the term "return" is required. To insure that the reader is aware of the context used by the authors throughout this document, the following definitions are provided:

- A *ground* is a large conducting body whose number of free charge carriers is sufficiently large relative to any current in the system that its absolute voltage potential does not measurably vary at any time. Two types of *ground* are commonly found in electronic systems:

  - The *reference ground* is a ground that, by careful design and implementation, carries as close to zero current as possible at all times such that it forms a systemic zero point voltage reference for all subsystems at all times.
  - The *safety ground* is a ground that, under normal conditions of operation, carries no current but is designed and chosen such that under any foreseeable fault condition all unintended current flow caused by the fault flows in the safety ground to the earth ground, which is a sub-milliohm connection to the largest ground body available (typically a copper rod driven multiple feet into the soil).

- A *return* is the conductor that carries the image current equal and opposite to the desired signal current that flows in the "hot" or "supply" conductor. A common example is a power supply, where the colored wire is the "hot" and the black wire is the "return."

The purpose of the grounding scheme described herein and all good wiring practice for noise control is to reduce the current in the reference ground to as near zero as possible by insuring that the return currents for every signal are as completely as possible carried on the return wire for that signal.

Interconnected Modular Segments

Each major detector subsystem of the BTeV detector that moves into or out of the C0 building is considered a segment. Each segment uses its large metal body as the reference ground for that detector subsystem. Multiple low inductance connections (e.g., wide copper sheets and/or braids) are used to connect each segment together once installed in place to create a contiguous reference across the detector.

Other segments include the under-floor reference grid found in each counting room, the metallic bodies of the high-voltage and monitoring system, first and second floor extension areas, and the cable trays used to deliver DC power between the counting rooms and the detectors themselves. When fully installed, all of these metallic objects are electrically tied together to create a building-wide reference ground used throughout the experiment.

Each detector segment's reference ground shall be connected to the experiment's reference ground system with a minimum of two parallel connections. Each connection shall be designed to provide a connection with a total resistance of no more than 1 milliohm and minimal inductance.

Each counting room shall have a raised floor of the type commonly found in computer rooms, providing a minimum of 1-foot clearance above the actual counting room floor.

The first floor annex houses the High-voltage system. Since the High-voltage system provides floating potentials, the ground grid will be connected directly to safety ground. No signal processing will occur on this floor. The second floor annex will house signal processing electronics and therefore be connected to the reference ground. Several, low inductance connections will be made between the second floor counting house grounding grid and the annex grid. The monitoring system on each of the annex floors will be the same as that used on the counting house floors.

Cable trays shall be segregated into two types, those that carry DC power and those that carry signals. All DC power cable trays shall be manufactured of copper and shall connect the reference grounds of the counting rooms to the reference grounds of the detector segments.

Connection of Reference Ground to Safety Ground

The reference ground of each detector segment shall be connected to the safety ground using inductive coupling to isolate high frequency noise. Safety to reference ground loops will be prevented by the use of the grid system and the saturable inductor as described.

Safety Grounding

All AC panels and feeds shall provide a unique Safety Ground (the green or bare wire) that is distinct from the neutral (typically a white wire). Conduits, cable trays and other raceways carrying AC power shall all be metallic and shall be electrically contiguous with the Safety Ground contact point of the panelboard from whence they run. All wiring shall be done in accordance with current and applicable NEC and local codes. All wiring within relay racks or panelboards shall provide a Safety Ground connection capable of continuously handling the sum of all AC currents from all phases wired to that rack or panelboard.

DC power supplies shall all be Safety Grounded by connecting the case of the supply to the Safety Ground via a wire capable of handling the full AC current that may flow to the supply. All DC supplies with floating outputs designed to supply less than 50V differential between the outputs need not connect either output to the Safety Ground, although proper practice of connection to the Reference Ground is required. DC supplies of greater then 50V output potential are required to provide, at the output terminal that connects to Reference Ground, a resistive connection to Safety Ground of sufficiently low impedance that, should the supply fault at maximum output current, the voltage drop across that resistance is less than 50V. The resistance used for such fault protection shall be capable of dissipating the total fault wattage indefinitely.

Metallic portions of raised floors are required to be connected to the Safety Ground using a copper wire of no less than 4AWG, connected to a minimum of two points at opposing ends of the floor.

Cable trays shall be segregated into "power" and "signal" types. "Power" cable trays carry only DC power supply cables and "Signal" cable trays carry only differential signal or fiber optic cables. "Power" cable trays shall be of low-resistivity construction and all shall connect redundantly at both ends to the Reference Ground (and via that connection, to the Safety Ground). "Signal" cable trays shall be of non-conductive construction.

BTeV Detector Reference Ground: avoiding Ground Loops

The use of a Star routing structure for grounding prevents ground currents from running past sensitive electronics in an uncontrolled fashion. A Star routing configuration is realized by providing each subsystem with a unique return path to ground thereby minimizing subsystem interference. Each sub-detector discusses the particular details of that systems grounding. This section covers the philosophy of grounding the subsystems for a coherent overall scheme.

Inter-system connections should ideally be via fiber optic cables. The use of fiber optics completely eliminates the ground return current problem arising from data transmission. For cable runs that go from the pit to the counting room only fiber optics should be used. Cabling between sub-systems is preferably fiber optic, however, other considerations may dictate the use of copper. Section 8 discusses the grounding of copper signal cables.

Connections from Detector Electronics to Reference Ground: Relay Racks

The method used to ground electronics racks and subracks is shown in Figure 13.7.

All electronics racks are tied to the reference ground by a low inductance connection to the underfloor reference ground grid. These connections must be made of sufficient gauge to carry the sum of all AC current feeds into the rack since this connection also acts as the safety discharge path.

Each subrack chassis has an internal connection to the most common return plane on the associated backplane. Each backplane is connected to the electronics rack with a short jumper. Subrack mounting screws are not considered an adequate connection.

The power supply chassis is connected to the electronics rack via a short jumper. The rack is connected to the reference ground grid system thereby, completing the path.

Connections from Detector Electronics to Reference Ground: Cable Trays

Two types of cable trays will be used in the experiment, shielded and unshielded. Shielded trays are made of conductive material with fitted lids that are secured with non-oxidizing contacts. Unshielded trays will be constructed of non-conducting material.

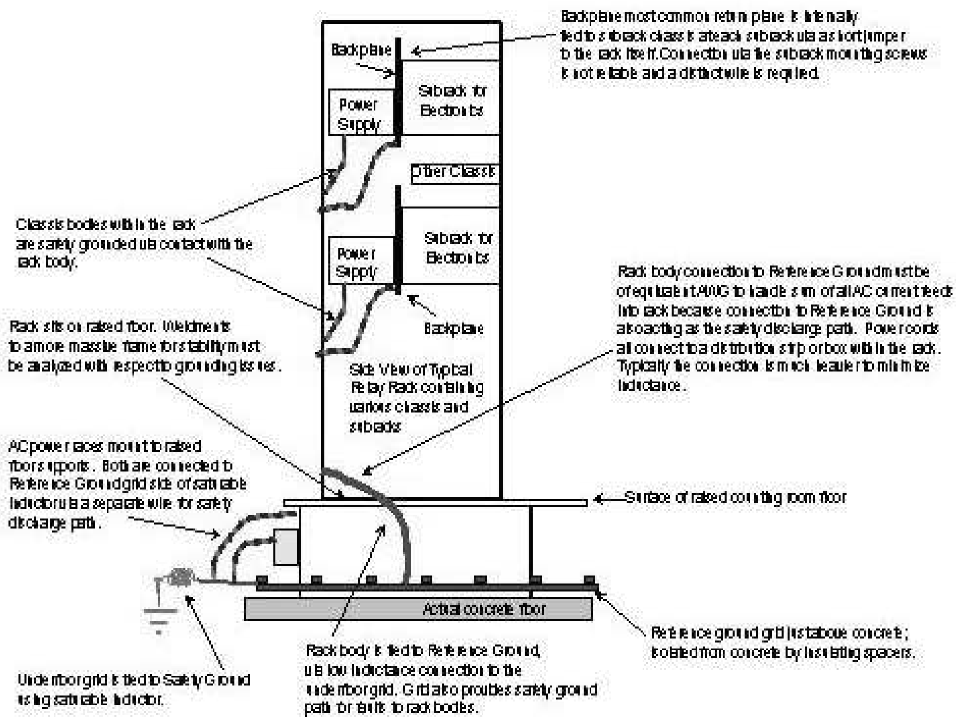

Figure 13.7: BTeV grounding scheme.

Shielded cable trays are tied directly to the reference ground floor grid network throughout the experiment. Sensitive analog signals and power cables will be run in separate shielded trays. Unshielded trays will be constructed of non-conducting material. Unshielded trays are used for differential pair and fiber runs.

Provisions for North-South, East-West, and Up-Down cable installations will be addressed. The trays will be easily accessible for maintenance and new installations. Shielded trays are equipped with robust lids that will withstand multiple removal cycles. Safety system cable trays are easily visible and accessible. The tray system will be designed with expandability in mind.

13.5.6 AC Power Distribution

All power systems within BTeV are distributed using three-phase delta connections from the mains coupled to transformers with wye-connected outputs to drive each major subsystem. Readers of this section are reminded that "ground" within this section refers exclusively to safety ground; the reference ground is connected to safety ground prior to anything described herein.

The default configuration for all main power shall be 220 VAC, three-phase with neutral (wye). The main power shall be controlled using remote trip circuit breakers. Each counting room and associated annex area shall have “crash buttons” that, when depressed, release the remote trip breaker disconnecting all equipment power from that area.

A 250 kW diesel fired backup generator sufficient to run the entire building and all detector electronics for a minimum of twelve hours shall be present. The associated pad, ducts, and transfer switch are an integral part of this system. Switchover shall occur automatically upon failure of the mains. Tests of backup generator performance shall occur periodically.

Each major subsystem shall have its own Faraday shielded transformer to minimize the possibility of large ground loops over which high frequency signals may flow. Transformers may not break the contiguity of the safety ground. Sub-distribution is 208 V, 3phase done on a rack-by-rack basis. The maximum power to any rack is 10 kW (30 A, 208 V, 3phase). From the 208 V, 3phase each rack can tap 120 V, 1 phase and/or 220 V, 1 phase as required.

Equipment Rack AC Power

All equipment racks shall contain a Rack Protection system that controls the flow of all AC power within that equipment rack. The Rack Protection system shall contain sensors to detect smoke, airflow, water flow, temperature, humidity and water drip. Upon sensing any trouble condition the Rack Protection system shall drop the interlock. Dropping the interlock shall render the entire equipment rack, except for the Rack Protection system itself, completely powerless until reset. The interlock mechanism will be appropriate for the expected magnetic field and/or radiation dose in the area. Each relay rack has a panic button to kill the AC power in that rack. This kill will remove all the power from the rack except the rack monitor system.

One double duplex outlet shall be provided to each rack to power the Rack Protection system. This double duplex outlet shall be mounted below the raised floor in each counting room or annex area to discourage use of this power for any other purpose. For racks located in the collision hall itself this outlet shall be color-coded via the use of a red outlet and/or painting the box red. Rack Utility AC shall be a separate, non-interlocked circuit fed from a separate breaker in the distribution panel. During safety inspections the equipment connected to Rack Utility AC outlets shall be inspected. Any equipment not part of Rack Protection systems connected to Rack Utility AC shall be disconnected.

Quiet and Dirty AC Power

Standard AC power feeds to the experimental area and counting room is 208V, 3phase. Two types of feeds are available - “Quiet” and “Dirty” AC. For critical systems a backup generator can be switched onto portions of the AC distribution. Some non-critical subsystems will be allowed to go down in the case of power failure. The critical subsystems will be evaluated on a case-by-case basis and an appropriate sized generator will then be specified.

Some systems, especially those using sensitive analog electronics, may require extra filtering to achieve optimal performance. Phase-to-phase and/or phase-to-neutral filtering capacitors may be installed at the distribution panel in these cases. No filtering capacitors shall be installed from any phase or neutral to safety ground.

The power to the experimental hall comes from a 150 kVA, 3phase shielded transformer. The transformer feeds a 400A panel that is the main power disconnect. This is the "quiet" AC power supply. From the 400 A panel there are feeds to four 225 A panels distributed along the experimental area walls. Such "quiet AC" installations shall be marked by the use of orange outlets.

The majority of AC distributions within BTeV are expected to be "dirty"; that is, with no filtering capacitance phase to phase. Three 75 kVA, 3phase transformers feed their own 225 A panels. These transformers are the "dirty" AC power. Two of the panels are in the counting room and one panel services the utility and other AC power needs of the experiment and C0 building. Such "dirty" AC installations shall be marked by the use of ivory outlets.

Load Balancing and Harmonic Currents

Subsystems are responsible for load balancing to insure minimal neutral current. The load balancing will be done by rack and also at the larger subsystem level. Each rack has a breakout box for changing the phase connections. Each subsystem utilizing more than one phase of AC power (e.g. anything three-phase or anything using 208VAC) shall be required to provide an analysis of power factor control and neutral current over the subsystem. Dynamic power factor correction is recommended where practicable. All inductive loads greater than 0.5HP are required to provide static power factor correction.

Periodic monitoring of neutral and harmonic currents is recommended for each panelboard at BTeV. As the electronic system evolves unanticipated balancing errors may lead to significant currents that may degrade detector performance, or worse yet, create a safety hazard.

DC Power Distribution and Grounding

Depending on the application, either linear or switching supplies will be used in the experiment. Switching supplies are preferred due to their high efficiency, reliability, cost, and relative lightweight. Analysis of each power supply subsystem must be made to insure that the load presented to each 3-phase AC branch circuit is sufficiently balanced to minimize current in the neutral wire. To accomplish this most efficiently all power supplies should be of the power factor correcting variety and AC-DC power supplies should all be powered from branch circuits that only contain power supplies and/or impedance protected fans; power supplies should never exist on the same AC branch circuit as motors or other significantly reactive loads.

Remote sensing, internal monitoring of voltage and current and over voltage protection is required on all supplies. All power supplies connect to the BTeV monitor and control system. The details of noise and regulation are determined by each subsystem's requirements.

Power supply systems are required to have UL / CE certification. All supply systems must be pre-certified by experiment-wide infrastructure group for performance under load. Prototype supplies and harnessing must be provided for the safety review. The supply design must also be pre-certified by Lab Safety committee prior to production. Supplies must provide interlock capability consistent with standard rack monitoring/protection systems. Interlocks and shutdowns must be autonomous. Microprocessor or software controlled systems are unacceptable.

13.5.7 High-Voltage Power Supplies

This section deals with the overall high-voltage system. The details of each sub-detector's specific needs are in the appropriate section. In this section we deal with the general features of the high-voltage system, its location, cabling issues and the safety and control of high-voltage. The experiment will specify an integrated high-voltage system that is modular in nature.

Detector Subsystem High-Voltage Supplies

The infrastructure provides the base HV power supply system. The system design minimizes the types of supplies used that, in turn, minimizes the number of unique test stands and simplifies subsequent training of operations personnel. Two general types of modular high-voltage systems are being considered, bulk and point-to-point.

In a bulk supply scenario, one supply provides enough power for the load and is then distributed based on detector requirements. The bulk supply can be positioned in an annex area whereas the distribution modules can be placed closer to the load. In a point-to-point scenario, each channel of high-voltage has a unique cable to the load. In either case, each channel must be accessible to the monitoring and control system. Each detector subsystem must address the cost/benefit analysis of the two architectures weighing the cost of cable versus the cost of space in the collision hall.

The same control and monitoring system is preferred throughout experiment. Minimally, the same system should be used throughout each detector subsystem. Remote AC shutdown, to handle crowbar issues, is preferred. Correct use of input and output filters as specified by the manufacturer are required. HV runs, from the first floor annex area, require filtering at the load.

The high-voltage system is outside the collision hall because of historical radiation tolerance issues at other Fermilab experiments. Since the currents in the HV systems are typically small, one can successfully feed the power from longer distances. The maximum HV feed in BTeV is 25 meters. If HPDs are used, the required 20kV feed will be located within close proximity to the RICH detector.

The high-voltage cabling is consistent with the types and connectors that are allowed specified by Fermilab safety. The cable's shields are grounded at the load. The power supply end has a safety ground that minimizes the potential for ground loops to be generated. The lengths of cable and the costs are detailed in the respective sub-detector sections of this document.

13.5.8 Low-Voltage Power Supplies

The Low-voltage power supply system design minimizes the types of supplies used that, in turn, minimizes the number of unique test stands and simplifies subsequent training of operations personnel. This provides the opportunity for sharing of spares between detector groups. Only commercial supplies will be accepted.

Listing of supply voltages, currents, and quantity for each sub-detector is in their respective section of this document. The general guidelines for the low-voltage supplies are here. The coordination of low-voltage supplies will minimize the maintenance and repair issues. Also, the guidelines for grounding should minimize noise and ground loop problems that have arisen in other experiments.

The same control and monitoring system is preferred throughout experiment. Minimally, the same system should be used throughout each detector subsystem. Remote AC shutdown, to handle crowbar issues, is preferred.

Low-voltage power supplies typically used to power electronics should be remote sensed. The supplies should accommodate a 1 V loop drop on the sense leads. This may have to be only 0.5 V on some low-voltage units The supplies will not have leads longer than 15 feet unless supplies are specifically designed for that condition. Long remote leads can result in supply regulation instability. All supplies will be tested with same loading and cable lengths as in real installation to insure performance when installed in the experiment.

The use of any special filtering for linear or switching supplies will be investigated based on the application. Proper shielding of board mounted DC-DC converters is essential. The correct use of input and output filters as specified by the supply manufacturer is required.

Cabling for low-voltage power supplies should be as short as possible to minimize IR drops and inductance in the leads. In the case of power being delivered to geographically scattered elements of front end electronics more smaller supplies should be used in preference to fewer very large current supplies. By segmenting the power ground loops should be better controlled and less change for noise to be coupled into the front-end systems.

Large high current supplies can be used to power sub-racks since the lead length can be kept short and the backplane nature of such systems does not lend itself to segmenting the power easily.

Making Maintenance Efficient

During the design phase of a power supply system, consideration will be given to the ease at which the supply can be repaired, in-situ, and/or replaced. Supplies in excess of 25 kg or requiring more than one person to service require prior approval of the infrastructure group. Use of mounting the supplies on rack doors and/or drawer slides are preferred. Ease of access will be considered when determining power supply placement.

Power Supply Radiation Tolerance

There are several types of problems to consider when determining the placement of power supplies. Total Ionizing Dose (TID), displacement effects, Single Event Burnout (SEB), Single Event Upset (SEU) and Single Event Latch-up (SEL) are being considered.

A study was performed on the radiation pattern in C0. Refer to document http://www-btev.fnal.gov/DocDB/0005/000508/001/AndreiU.pdf . The study found that the radiation exposure rate is low, under 10kRad, in the area considered for power supply placement. Past experience has shown that a typical commercial supply, like those used in the B0 COTS system, can tolerate a Total Ionizing Dose (TID) of 15 - 20 kRads. Since all semiconductor devices are affected by TID, careful consideration is taken when assigning equipment placement. The low energy neutron fluence was found to be lower that 10^{12} Neutrons/cm^2 which will be considered when evaluating displacement effects.

SEB affects MOSFET power devices over 150V, SEU affects digital ICs, and SEL affects CMOS devices. All of these issues will be considered in the experiment as a whole.

Magnets will be used as shielding for the power supplies but stray field effects on supply transformers will need to be investigated.

General Monitoring and Control

Remote enable/disable, voltage, cur rent, temperature, status monitoring, voltage adjustment, and over current trip can be part of larger power supply standard hardware. All supplies will have voltage and current trip threshold capability that are reset either remotely or locally. The preferred industry standard protocol is CAN or I^{2}C.

Provisions should be made, within all power supply system designs, to remotely reset the AC power delivered to each supply.

Alternate Proposal: Bulk DC Power and Local Regulation

Highly distributed power architectures (bulk AC-to-DC converter feeding many smaller DC-DC converters) has potential cost and/or maintenance advantages and will be considered were appropriate. AC vs. DC low-voltage power distribution has an impact on grounding (noise) and return currents can be, in general, more easily controlled.

13.5.9 Signal Cable Routing, and Grounding

Cable Routing Separation

The most important issue in routing cables is the coupling of noise from one set of cables to another set of cables. In addition to routing, implementing proper grounding techniques will reduce noise. The discussion below tries to minimize coupling and noise problems by offering techniques that address both issues.

High-voltage from low-voltage systems will be routed in separate cable trays. High-voltage cables may be subject to occasional breakdown. The energy can be significant and be coupled into data cables. The second issue with HV cables is safety. HV systems have safety systems associated with them and it is best not to mix any other cables with them.

Supply voltage systems from signal cables will be routed in separate cable trays to minimize coupling.

Physical separation of safety system cables from data cables will be utilized to comply with inspection requirements.

Reference Grounding of Cables

Fibers and properly terminated shielded twisted pair cables are preferred. For fiber runs, grounding, of course, isn't an issue. For shielded twisted pair cable, the distinction between a signal return and the shield is discussed.

A return is the conductor that carries the image current equal and opposite to the desired signal current that flows in the "hot" or "supply" conductor. Reference ground may not be used as a signal return path.

Intra-system connections that are not fiber should all be via shielded differential pair. The electric field shield for the preferred LVDS level signals, either foil wrapping or non-insulated drain, shall be terminated to reference ground at the end of the cable where the signal receiver is grounded. Refer to Figure 13.8 for standard LVDS differential pair termination.

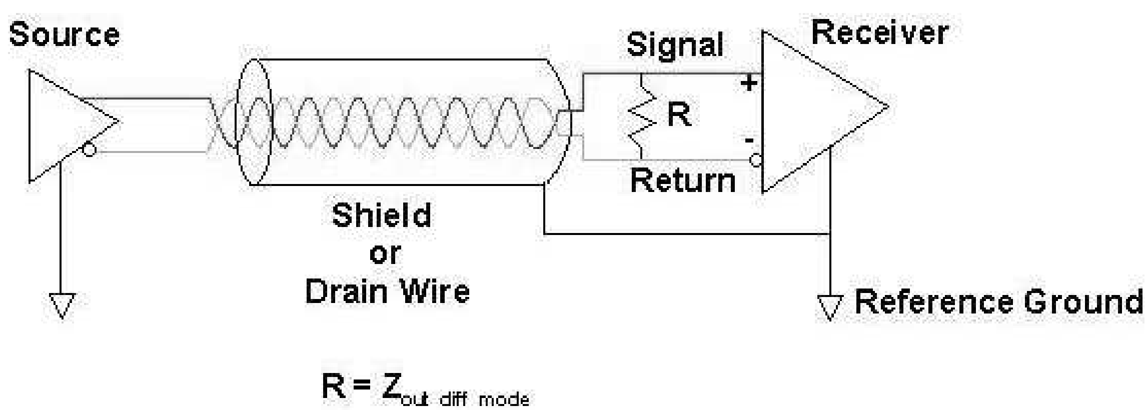

Figure 13.8: LVDS Differential Signal Termination.

For systems that must use RS-485, RS-422 TTL standard signal levels, refer to Figure ??

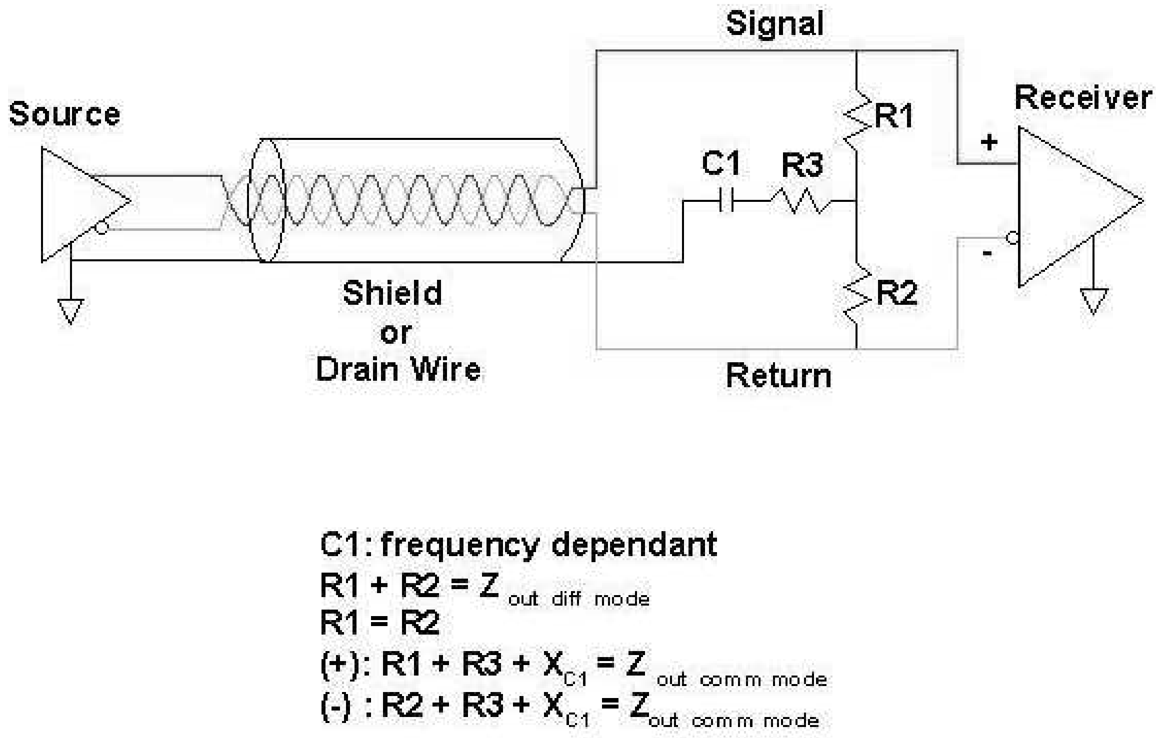

Figure 13.9: RS-485, RS-422, and Differential Signal Termination

13.5.10 Equipment (Relay) Racks Subracks

Equipment racks are mounted to or near each detector element. They will be in a two high configuration. A man lift will be used to access the upper racks, depending upon their location. Each rack in the stack will be completely independent to facilitate smoke detection in case of a fire. Space will be provided between them for top/bottom access of cables and other utilities.

A common rack system will be used by all BTeV subsystems. These relay racks will have 3phase AC power supplied to a breakout box. The breakout box will be configured to supply the necessary AC voltage to the equipment in that rack. The breakout box will be used to load balance each rack. These racks will have the BTeV standard rack monitor and safety system included.

Standard Cabtron relay racks, the same as those used at Fermilab, will be used in the experiment. All AC distribution, DC power supplies, rack protection electronics and items powered/monitored thereby shall be housed in one rack. Each rack will have four solid walls so that a single object can be monitored for smoke detection. For ease of access, power supplies will be mounted on the rear door.

A standard rack includes: subrack mounting hardware, blower, water manifolds, air/water heat exchangers, smoke detectors, leak detectors, air and water flow detectors, rack protection chassis, interlocked AC distribution chassis. Each rack will be equipped with an emergency crash button for personnel use. Sub-racks and power supplies are not included as part of the standard rack.

Individual detector groups shall procure subracks. The experiment-wide assembly/infrastructure group will install the racks. Standard rules are applied to all sub-rack installations to insure consistent grounding and adherence to safety considerations. Cooling and protection elements are consistent across all racks.

Rack Cooling

The preferred method of cooling is forced air up through heat exchangers and sub-racks. Single blowers in the bottom (or possibly at the top) of each rack with a speed sensor interfaced to the rack protection system are acceptable. The cooling system is designed to dissipate 10kW maximum. Subracks can dissipate a maximum of 2.5kW depending on its size and the design of the subrack electronics.

The water temperature must be kept above dew point. To comply with this requirement humidity monitors are required. Typical warnings are set at $> 70\%$ RH. 3-5 gpm H_2O flow ($\sim$3.5 degrees C per kW per gpm). Temperature monitors on heat exchanger inlet and outlet pipes are required. The temperature differential can be used to adjust water flow. The heat exchanger is connected to the rack water inlet and outlet manifolds. The manifold has a throttle valve on the outlet heat exchanger connection for adjusting flow - set to obtain a temperature drop of approximately 5 degrees C. This technique will properly cool the air and minimize the size of the water chiller.

Rack Protection System

The rack protection electronics can operate either remotely or autonomously. Each rack system has a local and remote reset and is monitored by the slow control system. The slow control system must comply with the configurable experiment-wide standard.

Items monitored by autonomous controls are the following:

- Smoke detector
- Water leak detector
- Blower Speed Monitor - The speed fault detection circuit has an integrator to insure the response is not too fast. Note that many new blowers have an integrated speed sensor that is compatible I^2C buses.
- Air Flow Monitor - (alternate to speed monitor?) Another method of blower monitoring is go/no-go sail switch for hard trip input. Solid-state airflow monitors are better than sails.

- Water Flow Monitor - The preferred implementation is one that provides visual or other differentiation between "no water" and "stuck impeller." The inlet/outlet temperature monitors on the heat exchangers can replace the water flow monitor at each of them. A rack flow monitor may be desirable.
- External fault inputs - a general set of inputs that can be monitored. They should be a 0 - 1-volt input.
- Temperature - several inputs for a rack. At least three for air in each bay and an inlet and outlet water temperature sensor for the air/water heat exchangers.

Power supply voltage, current, temperature, voltage adjustment should be part of the rack system. Most larger supplies have monitoring points. Smaller units may require monitoring points to be designed into the system.

Provisions should be made that allow equipment to be shut down due to external fault conditions. Examples are detector cooling systems and/or VESDA fire systems.

Each fault condition will be reviewed to determine if it is safe to reset remotely or if a visual inspection is required. Equipment that is not readily available for visual inspection will be identified.

13.5.11 Experiment Monitoring and Control Systems

Monitoring and control at the global level of necessity requires a consistent physical implementation and protocol. A simple method to achieve this is the use of standard network protocols such as Ethernet. However, care must be taken to insure that this implementation neither emits unwanted radiation nor provides inadvertent ground loops. A hierarchical structure utilizing commercial networks to processors organized to service unique geographic areas and the use of more specialized wiring from these processors to the areas served may be used as cost or noise control warrant.

The major safety systems require specific connection to Laboratory-wide safety systems. One computer of extreme reliability, separate and distinct from all other machines used for monitoring and control, is required for this connection. Typically a PC running a more stable and non-multitasking operating system than the usual desktop machine (e.g. not Windows or Linux, but an industrial OS) is used that receives the required status information using hardwired RS-485 connections and transmits the required data via the Laboratory-specific network (e.g. ACNET).

Each major geographic area of the BTeV experiment will be continuously monitored for temperature and humidity. In addition the collision hall itself requires monitoring for radiation and ODH hazards.

Counting rooms contain a large amount of electronics that are sensitive to temperature and humidity concerns. Excessively high temperatures and excessively dry conditions or those conducive to condensation may create situations where large amounts of electronics may be damaged. Continuous monitoring allows room air conditioning to be adjusted as required.

In addition to the requirements imposed upon the counting rooms, the collision hall must also be monitored for any oxygen deficient (ODH) conditions, sufficient airflow in any confined spaces and for radiation conditions. The radiation (luminosity) monitors need be interlocked with accelerator controls. Information regarding the conditions within the collision hall can and should be made available as a separate data packet for reporting to the main control room.

Power supplies are located throughout the experiment. All supplies should provide consistent monitoring features and control capabilities to insure operators understand actual supply status and to minimize extraneous access requests once the experiment is in operation. Every supply will, at minimum, provide the following feature set:

- Remote enable/disable of each DC output
- Remote measurement of supplied voltage and current of each output
- Remote measurement of supply operational temperature
- Digital information indicating any and all outputs disabled, and the reason why (overcurrent trip, over/undervoltage trip, external interlock, overtemperature)

Every power supply shall provide a remote method to reset any trip condition. This shall include any crowbar condition that the supply may find itself in and shall include remote enable/disable of the AC line input whenever required. Any such remote control of the AC line input shall be implemented in series with and may not interfere with safety system AC line shutdown.

All power supply monitoring and control should, whenever possible, be implemented on the same bus structure used to monitor the local environment that the supply is in. As an example, supplies within an equipment rack should use the same physical bus for monitoring and control, as does the equipment rack itself.

13.5.12 Facility Protection Systems

Facility protection systems follow different rules than experimental monitoring and control systems. Facility protection in general may not rely upon any software or human intervention to act and the connections must be fail-safe such that failure in any facility protection wiring (open or short) causes the interlocks to be dropped. Proprietary systems such as FIRUS have been developed to follow these rules.

The BTeV experiment shall connect to FIRUS using a minimum of one FIRUS node and console, monitoring at least 64 contacts. All detector systems shall provide inputs from the facility protection system that cause general interlock of all power sources in case of a FIRUS alarm condition.

All facility protection systems shall include connection to a console in the experiment control room that allows operators to monitor the system status and identify, when an alarm is issued, the source of the alarm.

High-Sensitivity Smoke Detection (HSSD)

The commercial HSSD system previously certified for use at other Fermilab experiments shall be used at BTeV. A minimum of four zones will be used within the collision hall. Relay closures from the HSSD system shall provide contact closures used as inputs to the FIRUS system. Each zone shall provide unique contacts for "early warning" (minor) and "danger present" (major) inputs, with each zone having uniquely assigned obscuration levels assigned to each output.

The minor and major alarm outputs of the HSSD system shall be hardwired into the experiment-wide interlocks such that all power sources in the zone are optionally interlocked for a minor alarm and always interlocked for a major alarm.

Flammable Gas Detection System

A commercial gas detection system with multiple heads, control panel and solenoid valves will be implemented. Upon detection of any gas leak or detector head failure a major alarm relay closure shall provide input to FIRUS and also close the solenoid valves. Heads shall be positioned at strategic points along the gas route to provide redundant monitoring.

Oxygen Monitoring System

The Fermilab proprietary system for oxygen monitoring shall be used. Multiple heads shall be distributed throughout the collision hall and any other areas identified as having oxygen deficiency hazards. Oxygen concentration levels shall be provided to the control room console. Levels below safe concentrations shall generate FIRUS alarms and cause annunciators to sound the alarm.

Other Facility Protection Safety Issues

Telephone systems and annunciators - including a paging system - need be installed to insure that persons in the collision hall and other areas may communicate with the control room and be advised of dangerous conditions. The paging system must provide a sufficient number of speakers distributed throughout the area so that personnel can hear and understand what is said over fan noise and in cramped areas. Telephones in the collision hall and other areas with large concentrations of electronics require amplified headsets.

Water sprinklers are a necessary part of fire response but present their own problems when combined with fans and electronics. Dry systems should be considered wherever personnel safety considerations do not prevent their use.

Care must be taken to insure that all fans are interlocked in any fire condition to control the spread of fire. While the interlock of AC power to the electronics already covers the fans used for electronics cooling, small air handling fans used for climate control within the collision hall and/or counting rooms must also be controlled.

13.5.13 Guideline Documents

The Electrical Design Standards for Apparatus Used in Experiments at Fermilab (over current protection, conductor sizes, power distribution, etc) document will be followed.

The Standards for Cables Used In Particle Physics Division Experiments document will be followed.

The Documentation Requirements for Electrical Safety Reviews document will be followed. An Operational Readiness Clearance (ORC) review is required for unattended operation of any equipment.

Fermilab electrical safety program (FESHM 50XX) specifically FESHM 5046 (low-voltage, high current distribution systems).

BTeV safety documents available on the web: `http://www-ese.fnal.gov/BTeV/ElectronicsProjects/ExpInstallSafety/expinstallsafety.htm`

13.6 Cooling and Air conditioning Systems

In Table 13.1 below, we show preliminary estimated heat loads at C0.

13.7 Detector Gas and Fluid Supply System

Table 13.2 shows the various fluids and gases that will be needed to operate the BTeV detector.Low Conductivity Water (LCW) for the magnets is supplied from the Tevatron LCW system in the beam tunnel. Chilled Water is supplied from xxx. The gasses are supplied from an above ground gas shed, which is shown along with all the connections in Fig. 13.10.

13.8 Survey Reference System

The Tevatron-based C0 coordinate system used for Collision Hall survey is a right-handed Cartesian coordinate system. The Tevatron beam centerline is defined by the center of the C0 Low Beta Quadrapole at a specified elevation. It should be noted that because of the vertical trajectory the beam take in C0, the Interaction Point is half-way between the upstream and

Source	Units	$\frac{Load}{Unit}$ [W]	Total [kW]	H_2O [kW]	Air [kW]	%H_2O	% Air	Loc.	H_2O
Magnets (1.1)									
Vertex Mag	1	480k	480					C.H.	LCW
Vertex Bus								C.H.	
Toroids	4	10k	40					C.H.	LCW
B2 Comp. Dipls	2	18k	36					C.H.	LCW
B2 Bus								C.H.	
Power Suppls									
Pixels (1.2)									
Readout chip	6000	0.5	3.00	3.00	0.00	100%	0%	C.H.	Chilled
Power Supplies									
Chiller(1 hp)	1	746	0.75	0.75	0.0	100%	0%		Chilled
Vacuum Pump								C.H.	
RICH (1.3)									
HPD's									
HPD elec.		0.002						C.H.	
Readout Elec.									
Power Supplies									
EM Cal (1.4)									
PMT base	10k	0.002	0.02					C.H.	
Readout Elec.									
Power Supplies									
Blower Motor									
Temp Cntrl Htrs									
Chiller(1 hp)									
Muon (1.5)									
Readout Elec.									
Power Supplies									
Straws (1.6)									
Readout Elec.									
ASDQ chip	6696	0.32	2.14					C.H.	Chilled
TDC FPGA(s)	6696	0.64	4.29					C.H.	Chilled
Power Supplies									
Chiller(1 hp)	1	746	0.75						
Strips (1.7)									
Readout Elec.									
Power Supplies									
Chiller(1 hp)									
HVAC									
Totals		509493.5	566.94	3.75	0.00				

Table 13.1: BTeV Heat Load Estimates

System	LCW	Chilled Water	Electronics Cooling	Dry Nitrogen	Dry Air	Straw Gas	Muon Gas
Magnets and Beam Pipe							
Beam Pipe Gate Valves	X				X		
Vertex Magnet	X						
Vertex Magnet Power Supplies	X						
Toroids	X						
Toroid Magnet Power Supplies	X						
B2 Dipoles	X						
Pixel Detector							
Substrate Cooling							
Secondary Vacuum Pump			X				
Motion Actuators							
RICH							
HPD Cooling			X				
HPD Inert Gas				X			
PMT Cooling			X				
PMT Inert Gas				X			
C_4F_{10} Filtration			X				
EMCAL							
Crystal Temperature Control		X					
Dry Gas Purge					X		
Muons							
Chamber Gas							X
Dry Gas Purge				X			
Straws							
Chamber Cooling			X				
Dry Gas Purge				X			
Chamber Gas						X	
Microstrips							
Ladder Cooling			X				
Dry Gas Purge							
Trigger/DAQ Electronics							
Counting Room		X					
Level 3 Rack Cooling							
Counting Room			X				
Level 1 Rack Cooling							

Table 13.2: BTeV Gas and Cooling Requirements

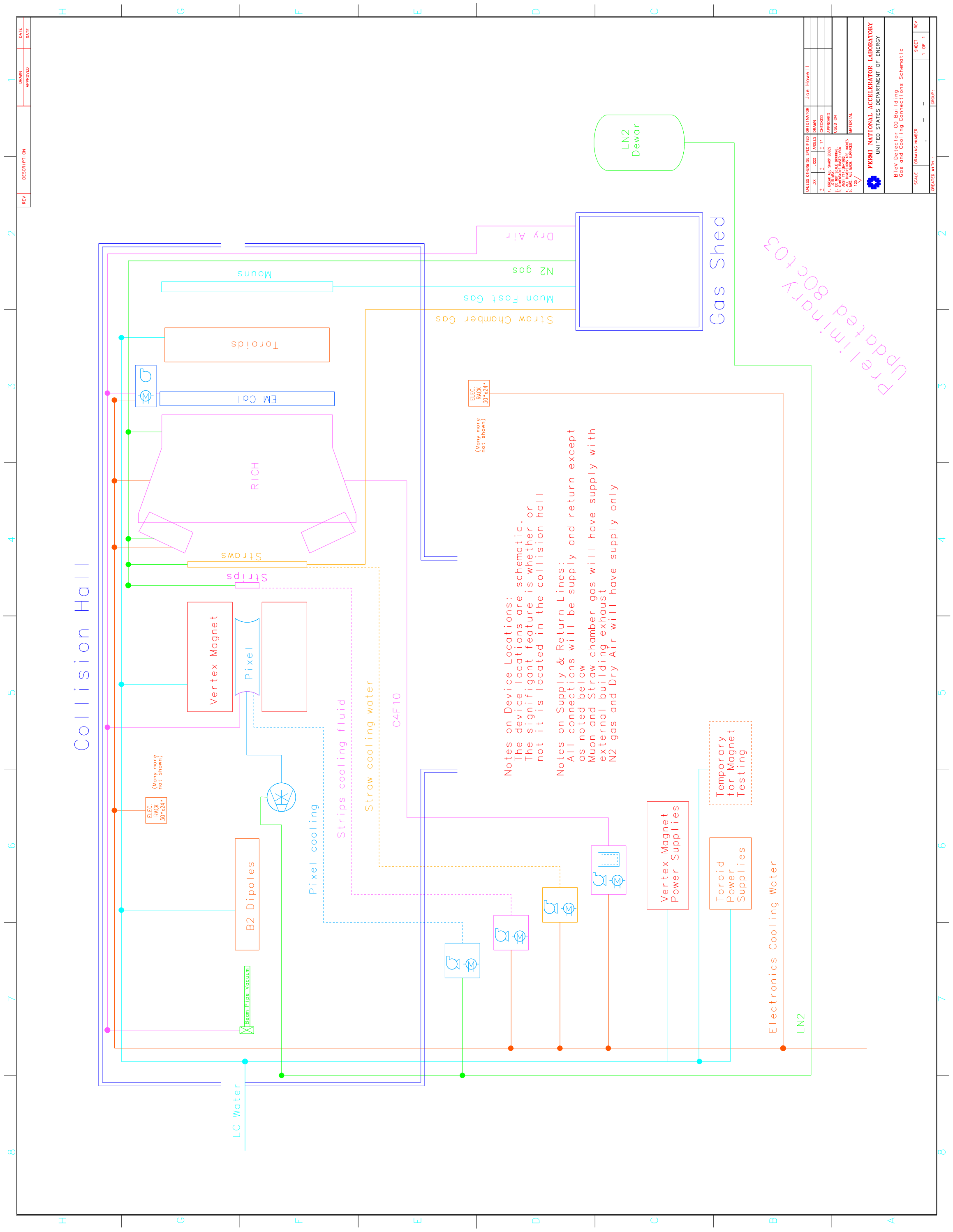

Figure 13.10: Schematic of the gas and cooling system connections.

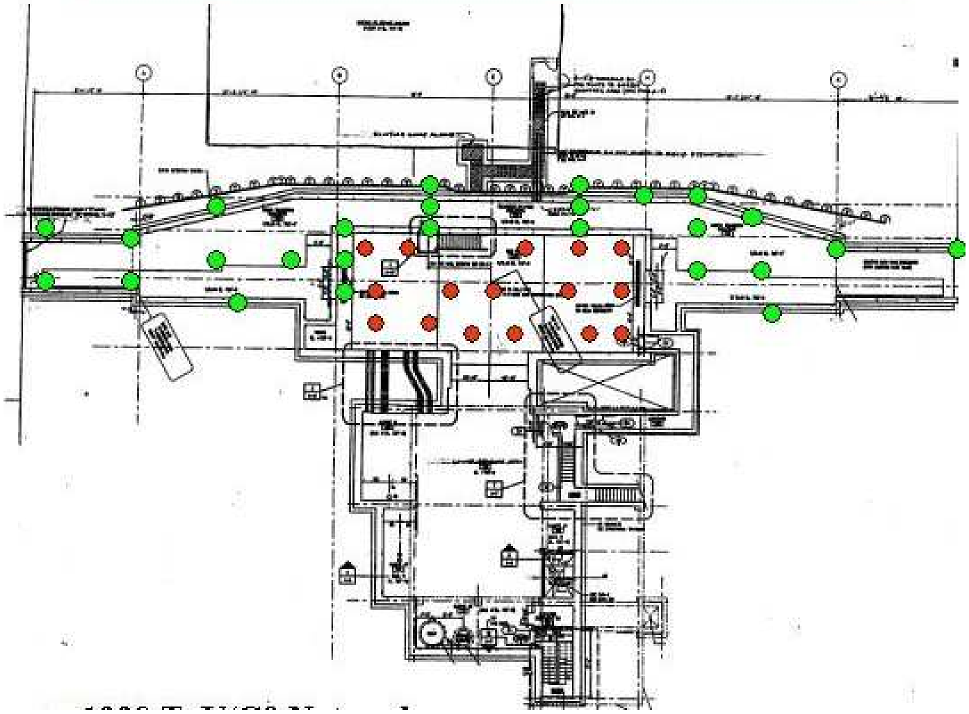

Figure 13.11: C0 Collision Hall Survey Network. The green points are the TeV/C0 network that was put in in 1998. The red points are the proposed C0 Collision Hall network that will be tied to the TeV/C0 network.

downstream quadrupole in the center of the enclosure but is 7.6 mm above the line joining their nominal centers. The Y axis point along the antiproton beam direction. The X axis points to the right of the Y axis and is perpendicular to it. The Z axis points positive up and is perpendicular to the X and Y axes.

The Collision Hall will have a “network” of survey reference points, shown in Fig. 13.11. The reference points consist of tie-rods along the wall at a height of 6’ from the floor for vertical reference and dead bolts on the open floor and wall for horizontal reference. All reference fixtures provide a receptacle for Laser Tracker and optical tooling fixtures, such as SMR’s (Spherically Mounted Retroreflector).

Three types of fiducials will be used for aligning the detector components:

- 0.250” Bushing Holes located at the corners of the component;
- 2×2 in^2 construction plates, with 0.250” holes in the center, welded to the component; and
- 0.5” Tooling Balls, used only if necessary.

Survey is accomplished with the following instruments:

- Laser Trackers, which use a laser distance meter and two precision angle encoders to calculate store and display the real-time three dimensional position of a mirrored target over the desired point or feature;
- V-STARs, portable non-contact three dimensional digital photogrammetric systems;
- BETS – Brunson Electronic Theodolite;
- Optical (Wild N3) and Electronic Levels (Leica NA3000) for elevation; and
- Stick micrometers for very short one dimensional distance measurements..

The BTeV Alignment Plan consists of the following steps:

1. Install all component fiducials and survey markers;
2. Reference detector components using Laser Tracker or V-STAR, or, in some cases, a CMM;
3. Establish the relative location of the components on a common support in the Assembly and/or Collision Hall using the Laser Tracker and V-STAR; and
4. Final survey in collision hall using the Laser tracker and V-STAR together with the Collision Hall survey network.

The alignment tolerances for the BTeV detector components are not very demanding. Typically, we would like transverse positions to be accurate to ± 0.25 mm and the position along the beam to be accurate to ± 1 mm. Internal alignment of the pixel detector components is much more critical and will be done with a CMM. Additional requirements will be placed on the roll, pitch, and yaw of chamber planes, mirrors, etc. Large, awkward components, such as the Vertex Magnet or the Toroids, will have more relaxed requirements. In many cases, small positioning errors do not have to be eliminated but do have to be carefully measured.

We will make sure that adjustments on all our support stands have adequate resolution and adjust-ability to achieve the required alignment tolerance. We will also make sure that all fiducials needed for positioning detectors in the hall will be visible when the full detector is installed. We will have methods for checking for settling of the hall relative to the beam tunnel and differential settling of the C0 Collision Hall.

It is worth noting that the experimenters have developed methods for using the data from recorded tracks to establish the relative alignment of detectors,to search for subtle rotations and non-uniformities, and to monitor alignment over time. These are used to correct the data for such problems. In BTeV, these program will be running continuously during data taking and the results will be immediately available to the experiment operators.

13.9 Lifting Systems

13.9.1 Assembly Hall Crane

The Assembly Hall and adjacent loading dock area is serviced by a 30-ton bridge crane. This crane will be used to assemble the large detector sub-assemblies in the Assembly Hall area. These sub-assemblies must then be rolled into the Collision Hall through the opened shielding door to the Collision Hall. A set of pneumatic pull rods with strategically placed floor anchors exists in both the Assembly Hall and Collision Hall to accomplish the needed maneuvers.

13.9.2 Collision Hall Lifting Devices

The Collision Hall is not equipped with a large overhead crane. The large detector sub-assemblies are designed so that they can be pulled into position with the pneumatic pulling equipment and can then be shimmed into their exact final location using standard rigging techniques.

For servicing individual detector elements and electronics racks, Man-Lifts will be available in the Collision Hall. The ceiling of the Collision Hall also has embedded Unistrut members that can be used as attachment points for chain-falls and other light duty lifting devices. The individual detector elements will be suspended from overhead tracks that project from the vertex magnet and toroid magnets. A-frame carts will be designed that allow the individual elements to be rolled into the Collision Hall and transferred to the overhead tracks.

13.10 Cable Runs and Supports

Cable trays will be suspended from the Collision Hall ceiling. There will be two sets of trays, one set of covered trays for the power cables and another set for the signal cables (most of which are optical fiber). The cable trays will run longitudinally in the Collision Hall to service the detector components and will connect to transfer cable trays that carry the cables to the east wall penetrations to the electronics areas in the C0 assembly building. The cable trays will be installed following all Fermilab Electrical and Mechanical Engineering and Safety Standards.

13.11 Overview of Installation

The installation of the BTeV spectrometer is governed by two factors: the limited space for assembly of subcomponents under the crane in the Assembly Hall, and the limited access to the Collision Hall due to ongoing Tevatron operations. The large components, the vertex magnet and the muon Toroids, must be assembled first and then rolled into the collision hall. This then provides the space for the assembly of the remaining sub-assemblies in the Assembly Hall, and provides the spectrometer backbone for positioning and supporting the remaining detector sub-assemblies in the Collision Hall.

It is assumed that, to the extent possible, all remaining sub-assemblies will have undergone a test assembly somewhere else at Fermilab or at a collaborating institution. This should help minimize the conflicts over space and time available to reassemble the sub-assemblies in the C0 Assembly Hall.

A survey of the positions of all components of the detectors and their sub-assemblies will be made in the Assembly Hall. After installation in the Collision Hall all detector components and sub-assemblies will be surveyed again. A final precision survey of the fully assembled BTeV spectrometer will occur after all components are installed and after about a month has elapsed to allow for settling of the detector in the Collision Hall.

13.12 Installation of Individual Detectors

13.12.1 Toroids

The large toroid assembly involves 30-ton iron slabs and welding operations and hence will monopolize the Assembly Hall floor space during their construction. After completion and testing, they can be rolled towards one end of the hall to allow space for the assembly of the vertex magnet. All applicable mechanical and electrical safety standards will be followed during the assembly of these large devices.

The Toroid Magnet will be one of the first elements of the BTeV detector installed in the C0 Collision Hall. The large weight will cause a general depression of the C0 Collision Hall with respect to the Tevatron accelerator. Since the BTeV muon detector system will be mounted either directly on, or at least with reference to the Toroid Magnets, provision must be made for regular surveys with respect to the Tevatron accelerator coordinates.

The assembly procedure for the toroid magnets with their embedded compensation dipoles are discussed below and in Figs. 13.12 through 13.16.

Step 1: Weld two bottom slabs (4.5" thick-Slab5) together per the designated requirement, move the slabs to the designated location. The bottom slabs of two toroids shall meet the following tolerances: The distance between 2 central lines in z direction (beam direction) of the toroids dc = 55.125" (+/- 0.0156"), the gap distance between two toroids (in yx plane) dg = 21.125" (+/- 0.0156"), the top surface (in zx plane) must be leveled within 0.0156". The weight of each Slab5 is: wsb5 = 0.94 tons.

Step 2: Move four trapezoidal shape slabs (Slab1) to the top surfaces of Slab5. Before starting to weld them together in pairs and then with Slab5, check the distance between downstream yx surface of the upstream toroid and the upstream yx surface of the downstream toroid; check the flatness of the xz surfaces; maintain the height (Y dir.) of the xz surface within +/- 0.0625". The weight of each Slab1: wsb1 = 23 tons.

Step 3: Move four support brackets by crane, align the 45^o surfaces of the bracket matching the 45^o surfaces of the Slab1. Before welding the brackets to Slab1, align the bottom surfaces (in xz plane) within 1/32"; central distance of the hole in Z dir. dZ = 55.125 (+/- 0.031"); the height of the bottom surface of the bracket in Y direction hy = 52.375" (+/- 0.063"). The weight of the each support bracket wsb = 1,322 lbs.

Step 4: Move four middle central slabs (Slab3) to the center of the top surface of Slab1. The surfaces in yz plane must be lined up within 1/64", check the height of the top surface of the slab in Y direction and make the adjustment if it is necessary. The weight of the each Slab3: wsb3 = 0.72 tons.

Step 5: Move eight rectangular slabs (Slab2) to both sides of Slab3 in yz plane. Besides to keep the geometrical and dimensional tolerances as stated from step 1 to step 4, it is also important to keep the central pocket dimension dx = 16.25" (+/- 0.010"). Weld Slab2 to Slab2, Slab1 and Slab3 per the requirements. The weight of each rectangular rectangular slab: wsb2 = 14 tons.

Step 6: Four 3" thick lower part plate slabs (Slab4l) will be placed on the outside surfaces on yx plane of Slab1, Slab2, Slab3 and Slab5. The aisle distance daz = 15.125" (+/- 0.0156") which is the distance between the downstream surface on the yx plane of the upstream toroid and the upstream surface of the downstream toroid in Z direction. The weight of the Slab4l: wsb4 = 6.9 tons.

Step 7: By using the specially designed crate for handling, move each of the four 10 turn coils carefully to the respective east and west location, use the appropriate brackets, shims and other accessories to align them to within engineering designated tolerances.

Step 8: With the crane, carefully move the B2 Compensation Dipole Magnet to the central U shape pocket between two coils. There will be about 0.179" clearance between B2 magnet and the coils in x direction. The protecting materials to prevent coil damage from impact from B2 magnet must be installed before any moving of the TM.

Step 9: Move four slabs (Slab3) to the top of the B2 Magnet, being careful to avoid contact with the B2. Align the Slab3 to let B2 magnet to have more than 0.062" clearance in +/- Y Direction. Also, check the top and side surfaces to apply the same criteria as stated from step 1 to step 5. Apply grove welds between Slab2 and Slab3.

Step 10: Move four Slab1 pieces to the top surfaces of Slab2 and Slab3. Align the slabs referring to step 1 and 2. Weld Slab1 to Slab1, Slab2 and Slab3. Move four Slab5 to the top surfaces of Slab1, weld Slab5 to Slab1 and Slab5 after the alignment.

Step11: Move four 3"-thick top part plate slabs (Slab4t) to the outside surfaces on yx plane of Slab1, Slab2, Slab3 and Slab5. Referring to Step 6, the surface on yx plane of the Slab4t must be aligned with the surface on yx plane of the Slab4l within 1/32". The aisle distance daz as defined on Step 6 must align to daz = 15.125 (+/- 0.015625"). Weld Slab4t to Slab1,Slab2, Slab3, and Slab4l per design instructions.

Step 12: Attach the Pre-assembled I-beams on the top of the toroid magnets with three weldments: w10 x 88 x 100, w10 x 88 x 40 and w10 x 88 x 15. Use 1/4" to 5/32" thick shims between weldments w10 x 88 x 100 and w10 x 88 x 15, also between w10 x 88 x 44 and w10 x 88 x 44. Move two pre-assembled I beams to the top surfaces (xz plane) of the toroid magnets, align two I beams to reach the following criteria: The central line of the weldment w10 x 88 x 15 in x direction must be aligned with the center line of the aisle within 1/32".

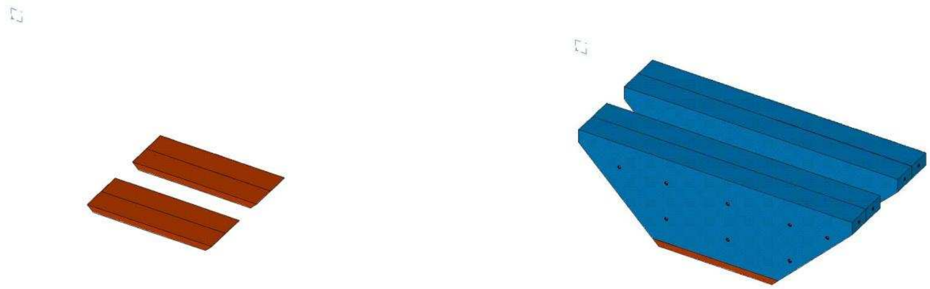

Figure 13.12: Toroid Assembly Steps 1 and 2

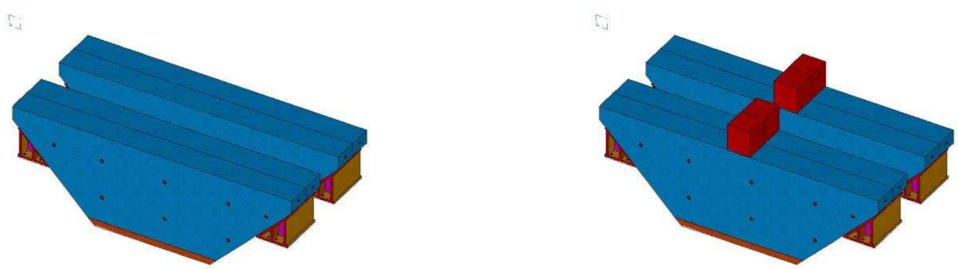

Figure 13.13: Toroid Assembly Steps 3 and 4

The unparallelism between two I beams in beam direction (z) must be within 1/32". The flatness of the major surface (xz plane) of the two I beams must be within 1/32". Weld I beam to the top surfaces of the toroid magnets per engineering requirements.

Step 13: Install the two pre-assembled rails which will be used for muon chamber detector supports by moving them to the top surfaces of two I-beams, use holding plates and boss plates to anchor to the specific location along z direction. Move the pre-assembled moving device of muon filter to the top of the surfaces of two I-beams; also, it should be installed in the downstream to the two installed rails of the muon chamber. The cam-rollers and its accessories will be installed at the last for the guidance and for locking the position.

Step 14: The crane will move 19.5 tons muon filter slowly to the designated location for connecting with its moving device. The downstream rail of the muon chamber to the filter will be installed last after the muon filter assembled to its mover.

Finally, the assembled Toroid Magnet of 400 tons is sitting on the C0 Assembly Hall, and is ready for moving to the C0 Collision Hall for Installation.

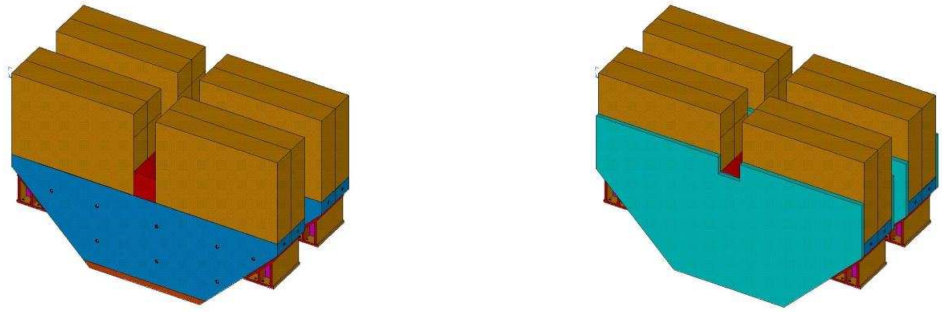

Figure 13.14: Toroid Assembly Steps 5 and 6

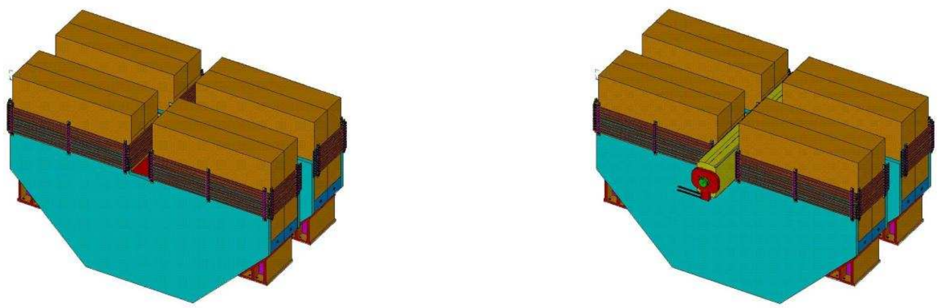

Figure 13.15: Toroid Assembly Steps 7 and 8

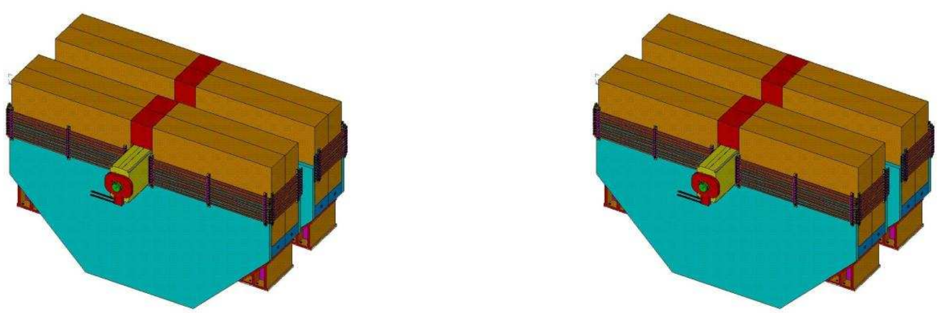

Figure 13.16: Toroid Assembly Steps 9 and 10

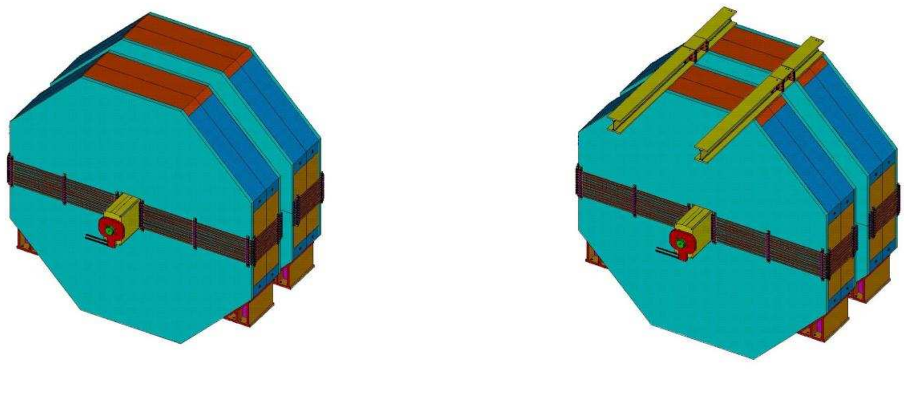

Figure 13.17: Toroid Assembly Steps 11 and 12

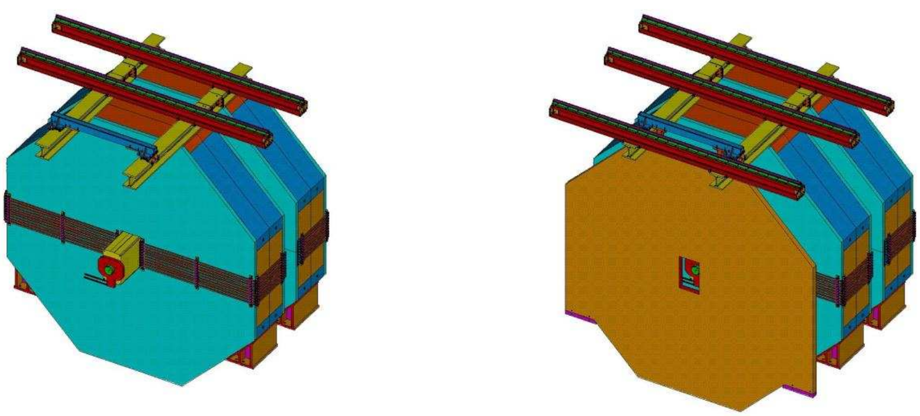

Figure 13.18: Toroid Assembly Steps 13 and 14

The optimum sequence for moving the vertex magnet and muon toroids into the C0 Collision Hall depends on details of the Tevatron operation schedule, the construction schedule of the magnet and Toroids, and the logistics of space usage in the C0 assembly hall. It is possible to interchange the order of installation of the magnet and Toroids, if schedules so require, without any overall impact on the spectrometer installation schedule.

The same four 500 ton Hilman rollers, Fig. 13.19, that are used for moving the collision hall shield door will be used for moving the Toroid magnet into the collision hall. The Hilman rollers will mount under two bridge beams that connect the two Toroid magnets at the bottom. The bridge beams have locations for hydraulic cylinders to mount for lifting the Toroid magnet pair for installation and removal of the Hilman rollers. The same hydraulic cylinders used for raising and lowering the shield door will also be used for the Toroid magnets.

The connection of the Toroids to the necessary power, LCW, control, and monitoring systems will be done under the supervision of Beams Division Electrical Department Staff.

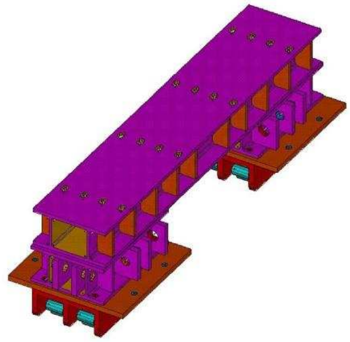

Figure 13.19: Hilman Rollers Used to Move BTeV Toroids and Vertex Magnet from C0 Assembly Area to C0 Assembly Hall

The existing ACNET control system and protocols will be employed and will follow standard Beams Division Electrical safety standards.

13.12.2 Vertex Magnet

This large assembly will also monopolize the Assembly Hall floor area during assembly. After completion, it will be connected to the power supplies in the Assembly Hall alcove and undergo an extensive set of magnetic field measurements using the Ziptrack magnetic field measuring device. After the measurements, the vertex magnet will be disconnected from the temporary connections used during the magnetic field measurements and readied to be rolled into the Collision Hall. Both the Vertex Magnet and the Muon Toroids are designed to allow the 500-Ton Hilman rollers from the Collision Hall shielding door, and the pneumatic pull rods in the two areas, to be used to move these assemblies. All applicable mechanical and electrical safety standards will be followed during the assembly of these large devices.

The Vertex Magnet will be one of the first elements of the BTeV detector installed in the C0 Collision Hall. The large weight will cause a general depression of the C0 Collision Hall with respect to the Tevatron accelerator. Since many of the BTeV detector systems will be mounted either directly on, or at least with reference to the Vertex Magnet provision must be made for regular survey with respect to the Tevatron accelerator coordinates.

The steps required to turn SM3 into the BTeV Vertex Magnet and install it into the C0 Collision Hall are the following:

1. disassemble the existing SM3 magnet in the Meson Area Detector Building and transport the pieces to the C0 Assembly Hall;

2. procure the pole-piece shims and additional fixturing;

3. reassemble, with the new pole piece shims, the SM3 magnet using the C0 Assembly Hall crane;

4. hook the magnet to temporary utilities and protection systems and map its field; and

5. move the magnet into the Collision Hall and hook up its utilities and protection systems.

In the following, we describe each step of this process.

13.12.2.1 SM3 Disassembly sequence and Transportation to C0 Assembly Hall

In this section, the SM3 disassembly sequence is presented in detail. The steps are shown schematically in figures 13.20, through 13.27. An associated plan shows how each piece of SM3 will be stored in the C0 Assembly Hall to facilitate reassembly with the 30 ton crane. The step by step storage plan is available elsewhere. The final position of the various pieces after the disassembly and movement of parts to C0 is shown in Fig. 13.28.

1. Disconnect and remove electrical connections, copper buss bars, wires (almost of them are on South Side) and gangways.

2. Dismount the upstream shield plate (SP), weight 3 tons, and the downstream shield plate, weight 3.2 tons, as follows:

   (a) cut or grind off welds between Spacer Posts and SP (the later should be connected to overhead 30-ton crane for support during this operation);

   (b) remove the basis bolts at the bottom of the SP;

   (c) set the SP on a trailer that has previously been backed onto loading dock at the East Side of the Meson area experimental hall;

   (d) transport the SP to the C0 site and offload it.

   This step is shown in Fig. 13.20(left) and is described further in a document titled "2 Iron Shield Plate for SM3" which provides detailed dimensions for the shielding plates.

3. Cut or grind off the welds between the Vertical Slabs and the Spacer Posts (the upper Spacer Posts should be connected to overhead crane for support before machining). See Fig. 13.20(right).

4. Bolt the Coil Support Brackets (CSB) (drw. 2850.28-ME-121695) to the face of pole pieces on West Side; Bolt the Join Beams (drw. 9204.300-MB-367785) to the Aluminum Support Plates (ASP); install jacks between CSB ASP. See Fig. 13.21(left).

   The weight is

Item	Approximate Weight	Number
Inner Coil	5.5 tons	2
Middle Coil	6.0 tons	2
Outer Coil	6.5 tons	2
ASP	2.6 tons	
Total Coils and ASP	38.6 tons	

5. Dismount the 17"-thick Slab (2 pcs) on East Side as follows: See Fig. 13.21(left).

   (a) connect the first Slab to the overhead crane (see lifting lugs on the top);

   (b) cut or grind off the welds between the first Slab and neighboring elements (10"-thick Slab, Bottom 10"-thick Plate);

   (c) when the Slab is free take it off the magnet;

   (d) set it on a trailer;

   (e) transport it to the C0 site and offload it.

   The dimensions of this slab is given in drw. 2850.28-ME-121740. The weight of the Slab is 27.2 tons.

6. Repeat the procedure described above to dismount the second Slab. See Fig. 13.21(right).

7. Dismount the 10"-thick Slabs (2 pcs) on East Side using the same procedure as was described for the 17"-thick Slabs above. Remark: in addition welds between 10"-thick Slabs and Upper Yoke Assemblies should be cut or ground off. See Fig 13.22(left).

   See drw. 2850.28-MC-121691, 2850.28-MC-121712 for the Slab's dimensions.

   The weight is

Item	Approximate Weight
85"	21.3 tons
42"	10.5 tons

8. Dismount the Upper Yoke Assembly (3 pcs) as follows:

   (a) cut or grind off welds between first and 10"-thick Slab on the West side;

   (b) when it is free take it off the magnet (the lifting lugs on the Assembly top should be used for the connection to the overhead crane);

   (c) set it on a trailer;

   (d) transport it to C0 site and offload it.

See Fig's. Fig 13.22(right) and drw. 2850.28-ME-121696 for the Assembly's dimensions.

The weight of the Upper Yoke Assembly is

Item	Approximate Weight
Type A	17.2 tons
Type B	17.5 tons

9. Remove the shims between the Coils and the Yokes.

   Using jacks, lift East Side of the ASP and Coils about 2" up.

10. Dismount the Inner 10"-thick Slabs on the East Side as follows: weld temporary Lifting Lugs (see drw. 2850.28-MC-121712) to the Slabs on the East (and West) Side;

11. Dismount the 85" wide Slab as follows:

    (a) cut or grind off welds between the Slab and the Bottom 10"-thick Plate, Slab - Lower Yoke Blocks (Slab should be connected to the overhead crane by the lifting lugs on the top);

    (b) cut or grind off welds (see drw. 2850.28-ME-121693 for explanation) between details #8 and #9, between details #9 and #1;

    (c) when the Slab is free, lift it about 1" up and move it to East a little, to avoid contact with the Coil;

    (d) set it on a trailer;

    (e) transport it to C0 site and offload it.

    See Fig. 13.23(left) and drw. 2850.28-MC-121691, 2850.28-MC-121712 for the Slab's dimensions.

    The approximate weight of the Slab (with pole pieces) is 22.8 tons.

12. Dismount the 42" wide Slab as follows:

    (a) cut or grind off welds between the Slab and the Bottom 10"-thick Plate, Slab and Lower Yoke Blocks (Slab should be connected to the overhead crane, by the lifting lugs on the top);

    (b) when the Slab is free, lift it about 1" up and move it to East little by little, avoid contact with the Coil;

    (c) set it on a trailer;

    (d) transport it to C0 site and offload it.

See Fig. 13.23(right) and drw. 2850.28-MC-121691, 2850.28-MC-121712 for the dimensions.

The approximate weight of the Slab (with pole pieces) is 22.8 tons.

13. Take off the Coils one by one (the Spreader bar must be used for coil handling). See Figs. 13.24(left) and 13.24(right). See attached sketch titled "SM-3 COIL INSERTION SPREADER BAR" and drw. 9204.300-MD-367791 for information.

    The Coils are to be saved in Meson Area (Detector Building).

14. Dismount ASP and CSB. See Fig. 13.25(left) for information.

15. Dismount 17"-thick Slabs (2 pcs) on the West Side as was done for the Slabs on East side (see paragraph 5 for the explanation). See Fig. 13.25(left) for information.

16. Dismount 10"-thick Slabs (2 pcs) on the West Side as it was done for the Slabs on East Side (see paragraph 6 for the explanation). See Fig. 13.25(right) for information.

17. Dismount the Inner 10"-thick Slabs (2 pcs) on the West side as was done for the Slabs on East Side (see paragraph 9 for the explanation). See Fig. 13.26(left) for information.

18. Dismount Lower Yoke Blocks (3 pcs) one by one as follows:

    (a) weld temporary Lifting Lugs on the top;
    (b) cut or grind off the welds between the Block and the Bottom 10"-thick Plate;
    (c) when it is free, take the Blocks off the magnet (the Lifting Lugs on the top should be used for the connection to the overhead crane).

    See Fig. 13.26(right) for information.

    The approximate weight of each Block is 12.7 tons.

19. Dismount the 10"-thick Support Plates as follows:

    (a) weld Lifting Lugs on the top;
    (b) cut or grind off welds in-between the Support Plates;
    (c) when it is free, take the Support PLates off the magnet one by one.

    See Fig. 13.27(left). The approximate weight of each Support Plate is 13.7 tons.

The final view of the dismounted magnet is shown in Fig. 13.27(right). See Fig. 13.28 for dimensions of the space used for storage in the C0 Assembly Hall.

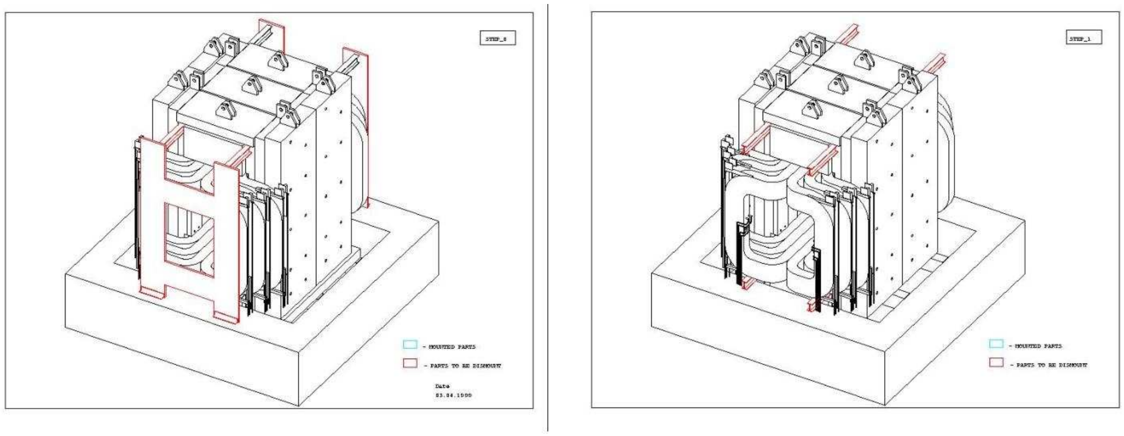

Figure 13.20: SM3 Analysis Magnet Assembly Steps 1 (left) and 2 (right)

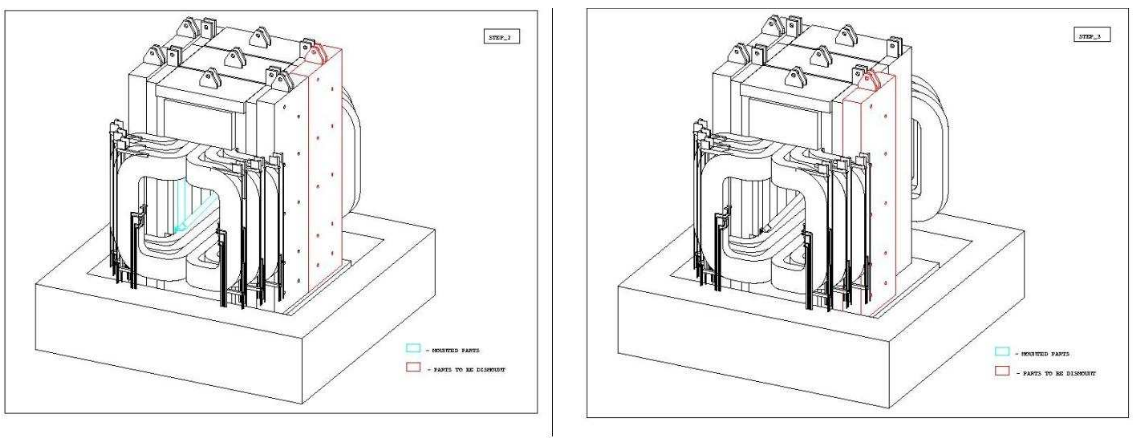

Figure 13.21: SM3 Analysis Magnet Assembly Steps 3 (left) and 4 (right)

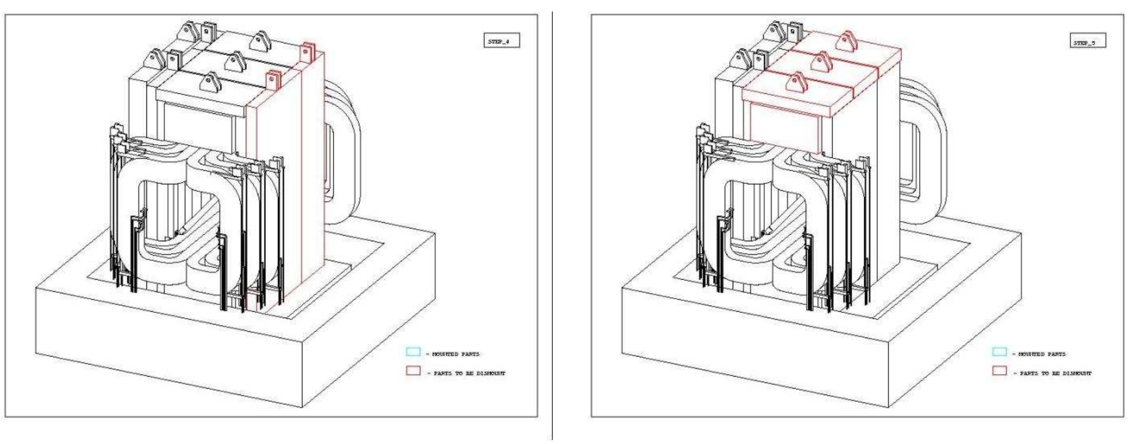

Figure 13.22: SM3 Analysis Magnet Assembly Steps 5 (left) and 6 (right)

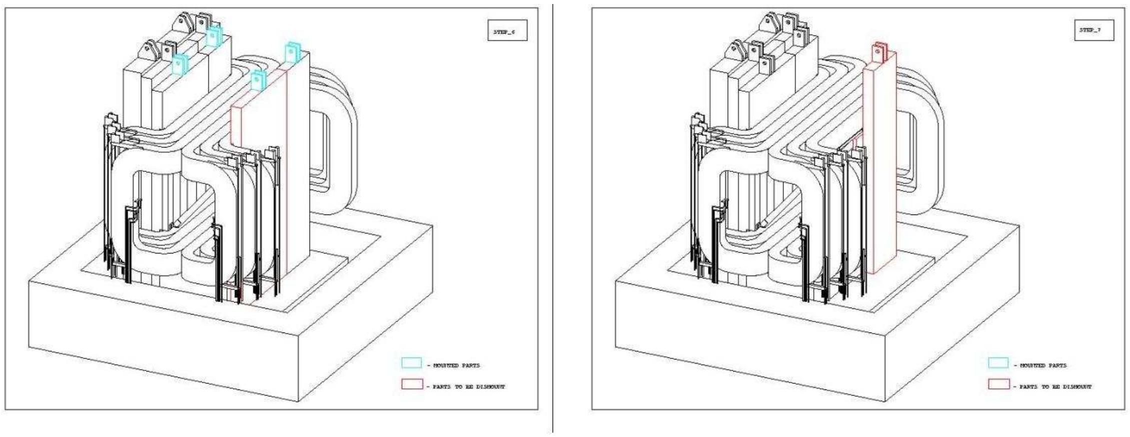

Figure 13.23: SM3 Analysis Magnet Assembly Steps 7 (left) and 8 (right)

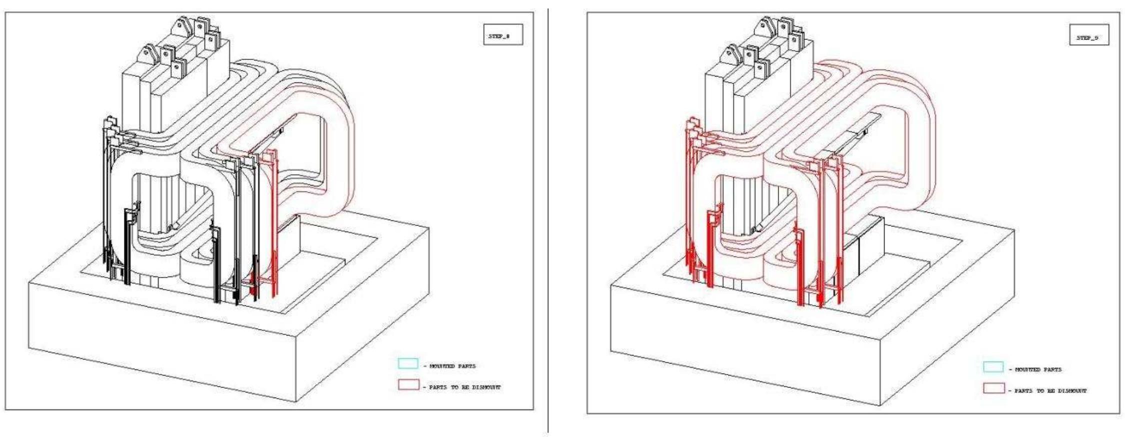

Figure 13.24: SM3 Analysis Magnet Assembly Steps 9 (left) and 10 (right)

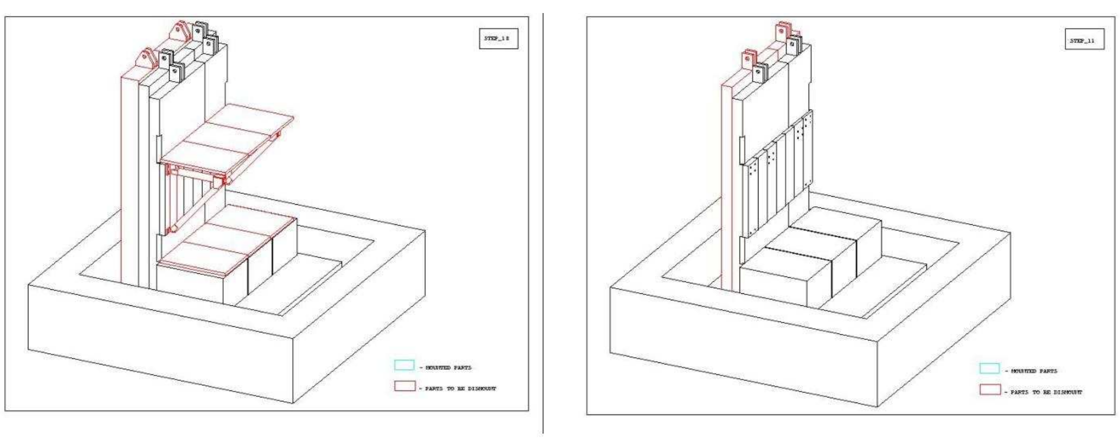

Figure 13.25: SM3 Analysis Magnet Assembly Steps 11 (left) and 12 (right)

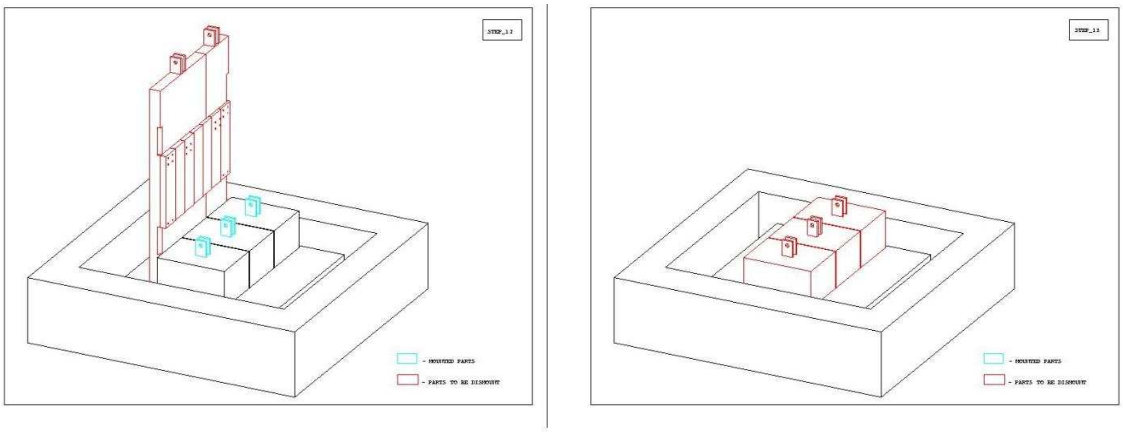

Figure 13.26: SM3 Analysis Magnet Assembly Steps 13 (left) and 14 (right)

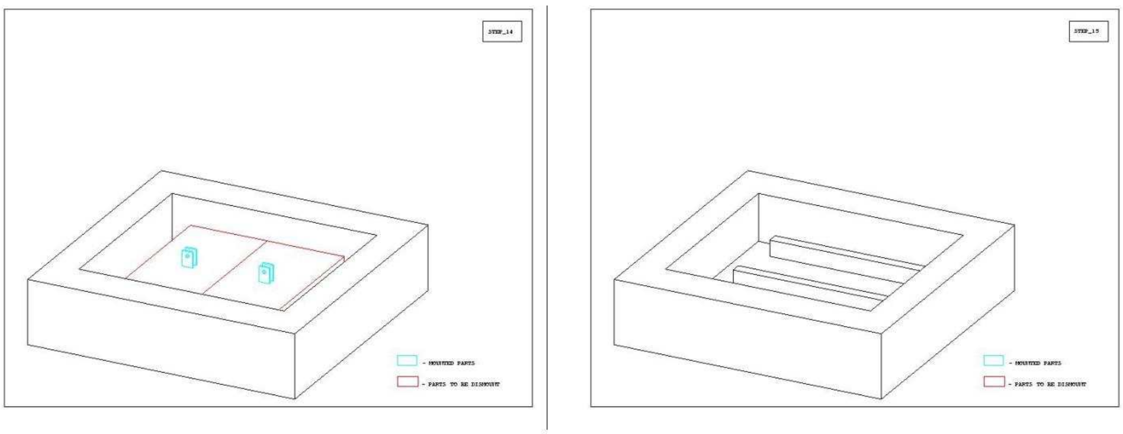

Figure 13.27: SM3 Analysis Magnet Assembly Steps 15 (left) and 16 (right)

13.12.2.2 Design and Procurement of Shims and Additional Fixturing

The prints for the fixtures fabricated to assemble the SM3 magnet in 1982 have been recovered. New fixtures needed to disassemble SM3 and reassemble it in the C0 Assembly Hall are being designed based on the original fixture design. The shims were designed using the magnetostatic computer code OPERA. They will be fabricated from high quality soft iron.

13.12.2.3 Reassembly of Magnet, with the new pole piece shims, using the C0 Assembly Hall Crane

The magnet will be reassembled at C0 under the C0 Assembly Hall 30 ton crane using a procedure that is almost exactly the reverse of the disassembly procedure given in detail above. The only major difference is that during steps 7, 8 and 13 of the procedure shown above, the new pole-piece shims will be substituted for the existing SM3 pole-piece shims.

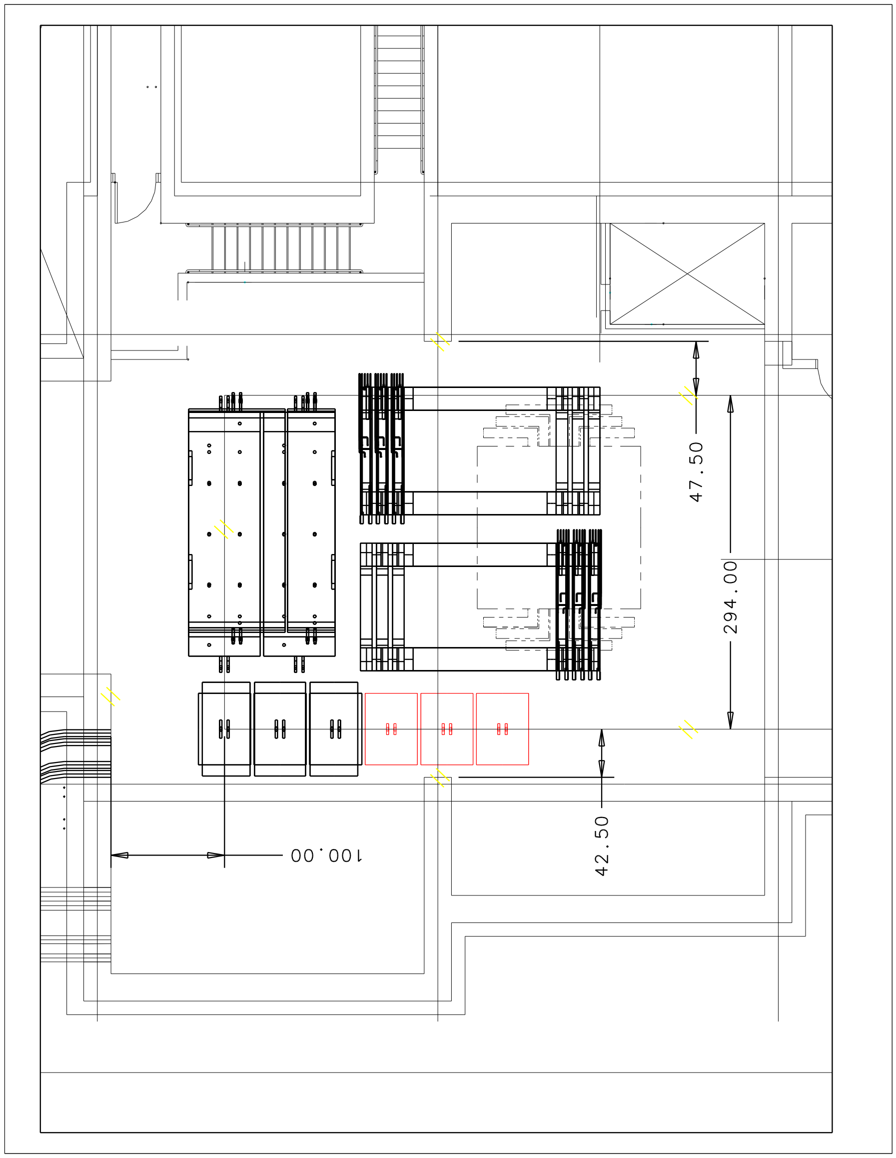

Figure 13.28: Plan for Storing Pieces of SM3 in C0 Assembly Area Prior to and in Preparation for Reassembly of the Magnet

This will also require a slightly different set of the aluminum support plate brackets used in step 11.

13.12.2.4 Connection of the magnet to temporary utilities and protection systems and mapping of its field

The magnetic field will be mapped while the Vertex Magnet is in the Assembly Hall. To do this, a short temporary connection from the power supplies in the C0 Assembly Hall to the assembled magnet will be constructed from water-cooled buss. The magnet LCW water will be connected to the LCW header in the Assembly Hall that also supplies LCW to the power supplies. The power supplies and controls will be connected and tested under the control of the Beams Division ACNET control system.

The Ziptrack magnet measuring system will be renovated, modified, installed, and used to measure the magnetic field of the assembled magnet over an extensive x,y,z, grid of points including the extensive fringe field region of the magnet. The data from the Ziptrack measurements will then be transferred to BTeV permanent data storage. The Ziptrack has been used recently by E907 at Fermilab [?] but will need some modification to measure the tapered pole insert regions of the Vertex magnet gap.

13.12.2.5 Movement of the magnet into the Collision Hall and hookup to its utilities and protection systems

The Hilman rollers from the C0 shielding door will be mounted on the magnet support structure and the magnet will be pulled into the C0 Collision Hall, using the existing C0 hydraulic cylinder pulling system, during a long Tevatron maintenance shutdown. The permanent water-cooled bus, LCW water connections, and control and safety systems will then be reconnected. After allowing two weeks for settling, the magnet will be shimmed into its final location on the C0 interaction point.

13.12.2.6 Power, Cooling, Control, Monitoring, and Utility Systems

The magnet will be connected to a pair of standard Beams Division PEI power supplies operated in series. The magnet will operate at 4200 Amps at 160 Volts. One supply will be operated in current mode and the other in voltage mode. The magnet and power supply cooling will be provided from the existing Tevatron tunnel LCW water system. This does not add significantly to the complexity of the existing system since there currently exist at C0 conventional magnets in the Tevatron lattice that will be removed for the BTeV installation. The existing ACNET control system can handle all the control and monitoring functions necessary to run the BTeV magnets without the need for system expansion. The C0 collision hall HVAC system has been sized appropriately to remove the heat radiated from the coils of the magnets during full excitation.

13.12.3 Muon Chambers

This section describes the installation plans for the BTeV muon system. The octants shipped to Fermilab will already have undergone a rigorous testing and quality assurance program at the production sites. They will be ready for installation and, unless they are damaged in shipment, ready to go.

13.12.3.1 Transportation of muon detector octants to C0

The octants will be delivered to C0 as they are fabricated at the production sites. They will be stored at C0 or some other appropriate place, and installed during periods in which we have extended access to the hall.

Equipment required: The octants which will be shipped to Fermilab will be too heavy to carry reliably without assistance. A roller cart will be required to move them. The required carts will be built in the Illinois machine shop and shipped to Fermilab and the other octant production site at Vanderbilt University. The octants will be shipped to Fermilab; we are still working out how this will be done. We will either rent trucks and move them ourselves, or ship them with a commercial carrier.

Special handling: The proportional tubes that make up the muon system will be made from stainless steel tubes strung with 30 micron gold-plated tungsten wire. The wires will be held in place with by crimped brass tubes at each end. The planks themselves will be extremely sturdy and strong, and the electronics and other connections internal to the octant will be very robust. The concern with the detectors is that some of the crimps holding the wire in place will fail or that wires will break, especially during shipping. This will be our major concern in determining how we will move the octants to Fermilab.

13.12.3.2 Installation of muon system elements at C0

The muon octants are designed so that they can be inserted from the wide aisle side of the detector hall. One dynamically creates a mounting "wheel." The first octant plate is inserted from the side and then rolled to the bottom position on a series of rollers that contact the octant plate circumference. The next octant plate is then attached to the previous plate using specially designed knitter brackets. One then rolls the two octant partial wheel into a position that allows the attachment of the third plate. Once all 4 plates of a wheel are assembled, the wheel is lifted off of the floor and mounted from beams attached to the toroid, as illustrated in Fig. 13.29 and the floor wheels (bogies) are removed and used for the installation of the next wheel. In all, 8 wheels are used for each station.

The process can be reversed for repairs. In the worse case, the replacement or repairs of a single plank will require de-cabling its wheel and sequential dismounting and rotation of the wheel until the affected octant is in a convenient position for repairs.

13.12.3.3 Installation steps:

Testing of octants on arrival: When the octants arrive at C0 from the production sites, we will retest them with the same test system used at the production sites: testing gas flow, current draw, readout of all channels, etc. Any problems will be fixed.

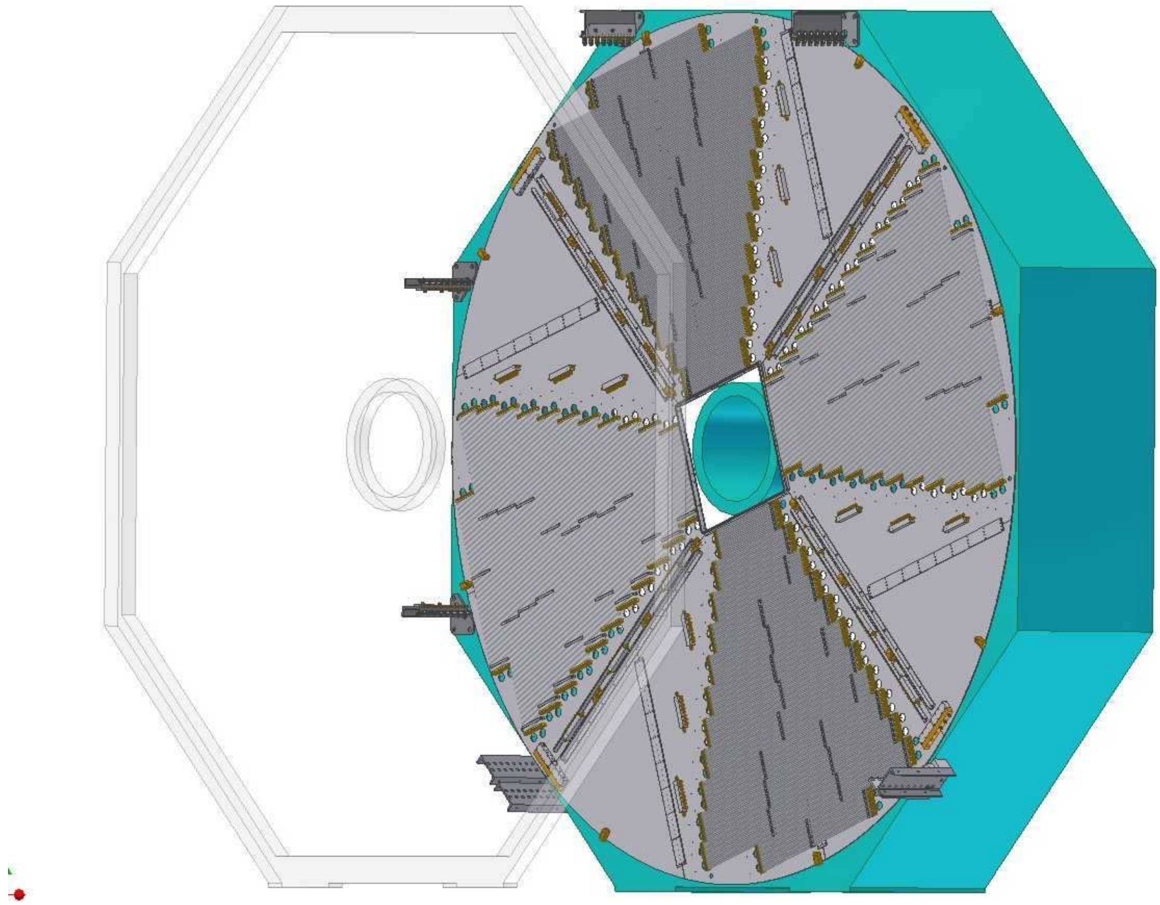

Figure 13.29: The mounting wheel will be supported from beams attached to the toroid. The upper two beams will support the ≈ 1500 lb weight of each wheel, the additional beams will prevent the wheel from swaying.

Installation of octant support structure: The muon planks will be assembled to octant plates which will then form "mounting wheels" during installation. These mounting wheels will be supported from the sides and top of the toroid and filter using a set of specially designed hangers which attach to fixtures on the wheel assembly.

Installation of relay racks, gas system, and other support infrastructure: We assume that the installation of relay racks and other support infrastructure (such as the gas system) will occur as early as possible. Low voltage and high voltage supplies, as well as data acquisition hardware, can be installed as needed (*i.e.* as new octants requiring them are installed, if possible).

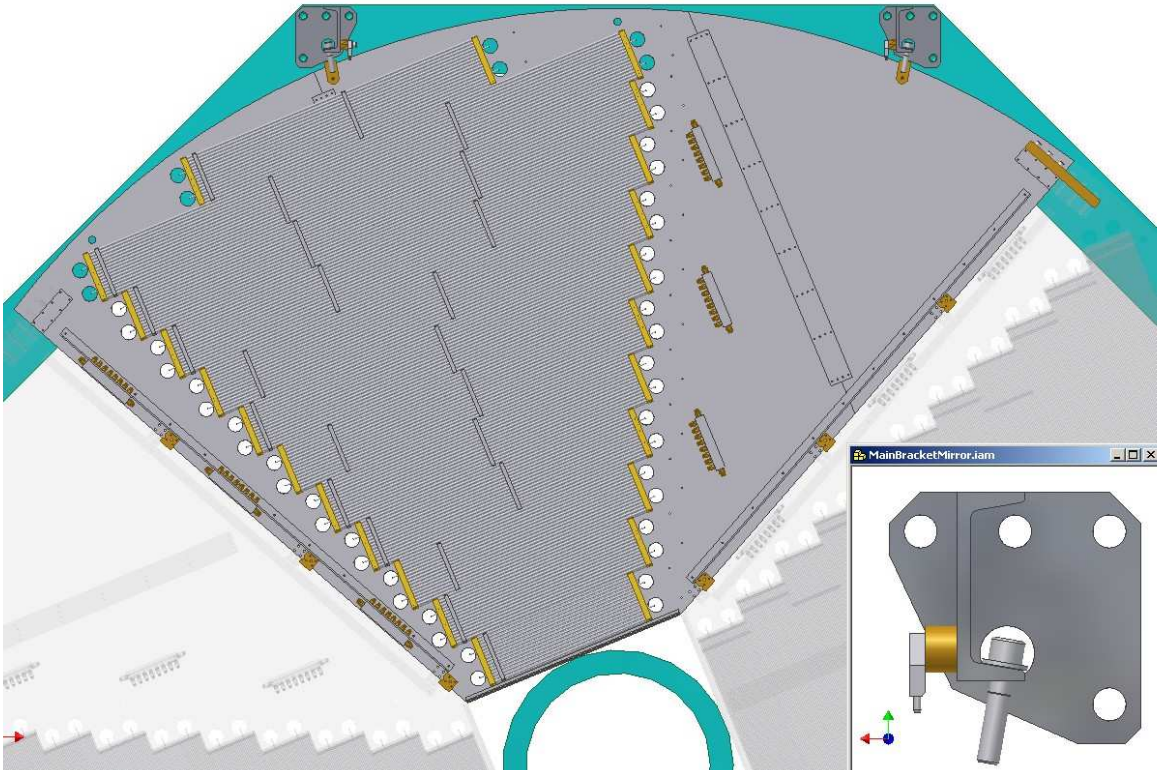

Figure 13.30: Details of the hanging brackets used to support the octant plate wheel assemblies.

Suspension of octants: The mounting wheel will be supported from beams attached between the toroids. The upper two beams will support the $\approx$ 1500 lb weight of each wheel as shown in Fig. 13.30. Additional beams will prevent the wheel from swaying. In principle, the muon system can roll with the toroid if one needs to move the toroids to service accelerator magnets.

We plan to install over a long period of time, as octants become available, and during extended shutdowns.

Low and high voltage, DAQ hardware installation: These items will hopefully be available as needed, *i.e.* as new octants are installed. We will install them at the same time as their corresponding octants, or ahead of time if they are available.

Connection of electrical, gas, and electronics: Once all the octants in a wheel are installed we make all gas, electrical, data acquisition, and slow control connections. We will then proceed to test these connections as described below.

13.12.3.4 Equipment required

For installation, special rigging will need to be assembled; again this will be provided by Illinois. This is envisioned as a special installation stand that will allow manipulation of each octant as it is being positioned into its mounting wheel.

13.12.3.5 Personnel required

The octants will be installed by members of the muon group. However, the support structure (beams) for the views will need to be installed by Fermilab personnel (welders, riggers,. . .). In addition, DAQ personnel may be needed to help with connection of the octants to the DAQ.

13.12.3.6 Time required

We estimate that it will take up to 12 hours to install each wheel of 4 octants, which translates to 4 days per station or 12 days for the full detector. This does not include connections, which we estimate will take an equal amount of time. We believe the time to install octants will decrease as we get better at it. Note that in real time this will take roughly two years, as we plan to install octants as they become available and as opportunities exist to gain access to the experimental hall for extended periods. The first octants should start arriving at C0 in the fall of 2006. The final octants should be ready by the fall of 2008.

13.12.4 EMCAL

Much of the mechanical structure will be assembled outside the C0 hall and brought to C0 by a truck. The entrance door to the C0 building is too small for the structure to pass either horizontally or vertically. A large forklift will be required to unload the structure from the truck and tilt it to 45 degrees for rolling through the C0 building door.

The partially crystal-filled structure will be pushed (pulled) on its wheels to the collision hall. It will be moved using a specially built transportation cart. Standard rigging equipment along with floor/wall anchors used for the magnets will be used.

Crystal-PMT assemblies will be brought to C0 in a box. We will need a simple lifting device (200 kg) to handle this box safely.

Crates (subracks) for housing FEB's will either be attached to the sides of the calorimeter structure or will be mounted in equipment racks.. We need to be able to handle these crates and racks (if racks are used). FEB's will be transported to C0 in boxes and will be installed in the crates after the crates have been installed and power tested. Access to the uppermost crates will require a ladder/platform or lifting device. In addition, bunches of cables (signal and HV), power supplies (LV and HV), and optical fiber bundles will need to be brought in.

Special Handling

Crystals and PMT's very breakable, and require careful handling.

Personnel Required

We will need riggers to unload the support structure from a truck and move it to the assembly hall or collision hall. We will need electricians to run AC power to the area where the crates are located. The rest will be handled by technicians, students and physicists.

13.12.4.1 C0 Installation Steps

- Close isolation gate valves and remove a section of the Beam pipe.
- Support structure will be rolled into place by riggers.
- Beam pipe will be reconnected. The support has to be rolled toward the muon toroid when RICH side of the beam pipe connection is made.
- Place electronics racks in position (if crates are not to be mounted to support structure)
- Run AC power to racks or to the support structure
- Install water pipes and heat exchangers
- Begin installing rack protection system
- Begin installing cooling fans
- Begin installing LV and HV power supplies and cables
- Begin installing data cables
- Begin installing crates and supporting infrastructure
- Set the table to temporarily keep crystal-PMT assemblies safely in place in front of the cells in the support structure.
- Place and adjust the height of the stage for installation people to stand/sit.
- Bring over a number of crystal-PMT assemblies to the table.
- Install the crystal-PMT's into cells in the support structure.
- Connect optical fibers.
- Connect PMT bases to PMT's
- Connect PMT bases to testing equipment.
- Test the crystals, and if any crystals are not working properly, fix
- Repeat the last five items as needed.

- When a crate's worth of FEB's are ready, install them. LV and HV supplies should be installed by this time, and connect them to PMT's and FEB's.
- Connect FEB's to a section of PMT bases
- Test the chain from crystals to FEB's using test-beam DAQ system.
- If there are any problems, fix them and re-test.
- Repeat the last 3 items as more FEB racks are available.
- When DAQ is ready, connect FEB output to DAQ, and test/fix.
- When temperature regulation system is ready, install it.

Equipment Required

We will need a stage for people to stand on when they insert crystals into the support structure. The height of this stage must be adjustable since the crystal position will run +- 1.6m from the beam line. We will also need a table with a soft surface where crystals can sit safely before they are inserted. The table should be right in front of the cells and its height should be close to the cells where they are going into to minimize crystal breakage.

Since optical fibers have to be connected to the crystals after running in the narrow space between PMT's, we are likely to need special tools for this connection.

We will need a device and technique to afford access to crates and infrastructure components mounted on or next to the support structure, high off the floor.

Special Handling

Crystals and PMT's very breakable, and require careful handling.

Optical fibers are also breakable, and need protection particularly after they are installed.

C0 Infrastructure Required

Minimum power is needed to test installed crystals on a daily basis.

If C0 air is too humid for stable operation of PMT HV system (small scale), dry air purging will be necessary.

Cooling water and heat exchangers will be required to operate large portions of the electronics. Individual crates may be able to be operated with only cooling fans and ambient air, but perhaps for only limited periods.

Before serious final testing which include stability tests, temperature regulating system must be operating, and this requires cooling water. The cooling water will need to be below 15 C and reject about 800 watts of heat gain from the room. A dry air purge source must also be available.

Potential Impact on Other Level 2 Subproject Elements: Assuming that muon toroid will be in place before EMCAL, it must be installed before RICH is in place. There will be no space to roll EMCAL if RICH is also in place.

Accelerator Impact of Installation

When the support structure is installed in the collision hall, a section of beam pipe must be disconnected.

Safety Issues

For handling of heavy objects (support structure is the most significant. The rest are 'standard' objects like racks of electronics, box of power supplies, bunches of cable.)

If we end up using dry nitrogen (less preferred) rather than dry air to purge the detector, oxygen depletion detection system must be in place and approved by safety people before it is operated.

The means we use to access equipment high up on, or near, the detector will need to be approved by Fermilab safety people.

Personnel Required

Technicians, students and physicists will be able to handle most of the work. When a box of crystals are brought in, for example, we may need riggers. Electricians will be required to install AC power to the detector.

Time Required

It will take three years. Mainly since crystals will become available a few at a time throughout the entire construction period.

13.12.5 Beam Pipes

The beam pipe assemblies will be thoroughly tested elsewhere on the Fermilab site. They will be brought directly to the Collision Hall and assembled as needed. The most important aspect of this procedure is the need to ensure that the Tevatron vacuum can be pumped down to its normal operating range, about 10^{-8} Torr, rapidly each time the beam pipe is let up to air.

There will be some stages during the installation of the BTeV spectrometer when the final thin-walled beam pipe is not installed, but instead, a temporary standard stainless steel beam pipe will be used. This ensures that the fragile beam pipe is not exposed during the installation of the large detector sub-assemblies, and that Tevatron operations are impacted as little as possible.

13.12.6 Straw Tracker

13.12.6.1 Summary of Testing Prior to Moving to C0

The Straw Detector will be assembled in half-views, including front-end boards and signal cables, and fully tested before moving to C0. Each wire will be tension tested and checked to see that it holds high voltage as it is strung, and then again when the half-view assembly is complete. Gas and cooling water lines will be attached and leak tested. The wire positions will be surveyed with respect to external fiducials on the half-view frames. Each half-view has an environmental sensor to monitor temperature and humidity; the readout from this will be tested. The functionality of the front-end electronics will be tested with pulses injected at the pre-amplifier inputs. The threshold voltages and other programmable registers will be set and read back. The full data readout chain will be tested with a radioactive source and/or cosmic rays.

13.12.6.2 Transportation of Straw Detector Equipment to C0

Equipment needed

All straw detector equipment will be staged at Fermilab Lab 3 prior to moving to C0. Equipment will be moved from Lab 3 to C0 by Fermilab Material Distribution Department trucks and drivers. The straw half-views will be transported in half-view transportation frames. The transportation frames will have outriggers for stabilization and will accommodate casters for local movement.

Special Handling

Relay racks will be transported with standard tie-down precautions. The straw half-views are somewhat delicate and may need to be transported via an air-cushioned transport. The half-views may also be connected to a dry gas purge source during transportation. A transportation procedure will be prepared for the transportation operation.

Personnel Required

The smallest half-view frames can be maneuvered by hand. The large frames will require some crane movement to lower them to the assembly hall floor. Qualified crane operators will be required. Straw group personnel will supervise all transportation steps.

Time Required

All relay racks can be loaded and transported in one-half day. The smaller straw stations (6 half- views) can be loaded and transported in less than one-half day. The larger straw stations may require one or two full days for loading and transportation.

13.12.6.3 Installation of Straw Detector at C0

Installation Steps

- In the C0 assembly hall three half-views will be assembled to form a half-station. The "three half- view" assembly will be transported into the collision hall and moved into position with a dedicated cart.
- The cart will have provisions for safely positioning the assembly onto a rail system that will allow it to be safely slid transversely around the beam-pipe. Two half-stations will be attached to the rails and connected to make a full station.
- The corresponding forward silicon station may be attached at this point.
- Power supply cables and signal cables will be attached, then the fully assembled station will be slid into the proper z position with a set of longitudinal rails. Once at the proper z position the station will be lowered a few centimeters and attached to more stable support brackets.
- The straw stations must be installed in the following order: 1,2,3,6,5,4. Station 7 will be treated separately as it is in a very confined space between the RICH and the ECAL.
- Gas and cooling water lines will be attached to the main C0 systems, power cables connected to patch panels and signal cables connected to Data Combiner Boards (DCBs).

– The positions of the straw stations will be surveyed using external fiducials on the half-view frames.
– Install gas monitoring system

Equipment needed

Cart to move half-views from assembly hall to collision hall, rails for sliding half-views into position

Special Handling

Straw station half-views are somewhat fragile and need to be handled with care.

C0 Infrastructure Required

Utilities required at C0: dry buffer gas (air or nitrogen) during installation; for testing chamber gas, water for cooling straw frames, HV and LV power

Potential Impact on Other Level 2 Subproject Elements

The pixel detector and beam-pipe must be fully installed before Straw stations 1-6. The straw stations must be installed at the same time as the forward silicon stations. The forward silicon will probably be supported by the straw frames. Station 7 is sited between the RICH and ECAL we will probably wait until both these detectors are fully installed before installing station 7.

Accelerator Impact of Installation

The straw stations will be installed around the beam-pipe.

13.12.7 Silicon Forward Trackers

Once micro-strip half planes are assembled and checked at SiDet, they are ready for the final installation at C0. It is worth noting that micro-strip half planes are already internally aligned to ensure a sufficient relative precision when combined to form a plane and even a station. This means that the most crucial operation during the installation is to position the first plane, on the basis of which the station is built. Micro-strip installation should be coordinated with that of straw tubes since micro-strips can be installed only once the straws of the same station are already installed. The installation of the full micro-strip system consists of seven almost identical procedures of single station installation. We estimate that each installation will take about one week, including a full check of all the station functionality and performance. Note that in real time, this will take roughly one calendar year, as we plan to install stations as their parts become available and as opportunities exist to gain access to the experimental hall for extended periods. The first station should be installed in early 2009. In the present base-line design, we foresee an independent support for each micro-strip station, but are trying to investigate the possibility to directly integrate the micro-strip support in the straw structure of the same station.

13.12.7.1 Installation Steps

The installation sequence for a single station consists of the following steps:

- Installation of the station support and all the connections to power supplies
- cooling system, and DAQ & control
- Installation of the first plane
- Installation of the second plane
- Installation of the third plane
- Installation of the station enclosure

Equipment Required

High accuracy survey equipment is required to measure the position of the fiducials on the station support and on the half plane structures, and to align them with respect to the external fiducials.

Special Handling Issues

All the components of the system are extremely fragile and should be assembled in a pretty clean environment.

Potential Impact on Other Level 2 Subproject Elements

Micro-strip installation is strictly correlated with that of the straw tubes. We plan to install micro-strips only once the straw tubes of the same station are already installed. Presumably both micro-strips and straws will share the same external mechanical structure, which can slide into the final position on high precision rails.

Personnel Required

The Micro-strip group will take care of the installation process. In addition, we need an expert to properly setup and check the links to the monitor/control system. Also we need the assistance of a survey crew during the installation to measure the position of the fiducials.

Time Required

We estimate that three days are enough to physically install one station and to carry out the obvious checks for continuity of the connections. Presumably the survey crew would need one day more to setup all the instruments. As stated in the introduction, it is worth noting that the real duration of the complete installation would be roughly one calendar year.

13.12.8 Gas Systems

The gas hut will be constructed outside the main C0 assembly building. It will be tested and certified as compliant with all the applicable standards for the storage and distribution of flammable gases. The piping for the various gases needed by the BTeV detectors can be installed as far as the Assembly Hall at any time. The final installation of the gas supply headers and exhaust return lines for each detector will take place during the many one and two-day maintenance breaks in the Tevatron operation schedule. The return gases will be vented outside the building following all the applicable Fermilab standards. Individual detectors will be hooked up to the gas system manifolds in the collision hall as they are installed. Before detectors are installed, the gas system elements will be checked for contaminants and cleaned/replaced as needed.

13.12.9 High Voltage Systems

The bulk of the HV power supplies are located on a catwalk or "counting room extension" over access door outside the collision hall and cabled into the C0 hall. Sufficient electrical support will be provided followed by the installation of the relay racks (see the lower left hand portion of Fig. 13.3 and the description of the AC Power Distribution). Additional racks for 20kV supplies will be installed in the collision hall after the installation of the large pieces of the RICH detector. The catwalk racks can be installed at any time.

A cable tray channel will be created in the top right-hand corner of the C0 Collision Hall shielding door by removing a row of concrete blocks from the top of the door. Additional transfer trays to the detector elements will be installed off of the top right-hand corner tray. Cables will be routed over the top of the shielding door through a labyrinth channel. The high voltage cables will be installed during appropriate

Tevatron operations maintenance days. The final installation will be inspected and certified for compliance to all applicable electrical and mechanical safety standards.

The High Voltage supplies which will come tested and certified from the PREP pool can be installed in a staged process where we first install the systems needed to debug the control and monitoring as well as test detectors as they are installed. I.e. it is not necessary to install all the high voltage supplies at one time, just enough to make sure the bulk of the installation will go smoothly,and that each installed cable and/or detector can be raise to its operating voltage.

13.12.10 Pixel Detector

The pixel detector will arrive at the Assembly Hall as a fully assembled and tested device. Further testing could be done in the Assembly Hall if the need arises. Rolling the Pixel Detector into the Collision Hall and installing it in the BTeV Vertex Magnet will require an extended Tevatron operations down period since the Tevatron beam pipe must be removed and reconnected for this operation. Also the various mechanical and cryo vacuum pumping systems associated with the Pixel Detector must be reassembled and made fully operational before the Tevatron can return to normal operations.

The first major step in the installation of the pixel detector system is the assembly, alignment and testing of the individual pixel stations. This will be carried out at SIDET. The pixel detector will then be placed inside the pixel vacuum vessel. End flanges will be placed at the two ends of the vacuum vessel which will then be pumped down before transportation to C0. Once assembled, all cables external to the vessel will then be coiled and properly tied in preparation for transport. The pixel vessel assembly will then be transported to the C0 experimental hall.

Work on the installation of the support system for the pixel vessel will be conducted in parallel with that of the pixel assembly. This will include construction of a rail system for rolling the assembly into position in the magnet followed by the installation of cables, cooling, vacuum, and connections for actuators, exit windows, and beam pipe. This work will take about 5-7 days, including testing of all the connections after installation. A full checking of the system including readout, cooling, vacuum, actuators etc. will take at least 4 months. After the pixel vessel has been installed, we can then proceed with installation of the forward tracker stations 1 and 2. This section describes the full chain of testing of the pixel detector after it has been properly installed at C0. The integration of the pixel system to the rest of the BTeV detector will be described in the integration section.

13.12.10.1 Tests before, during, and after assembly at SIDET

The basic building block of the pixel detector is a module, which is composed of a pixel sensor bump-bonded to a number of pixel readout chips. On top of the sensor, a high density flex cable (HDI) will be glued. The readout chips will be wire-bonded to the HDI and the latter will carry all the signal, control, and power lines from the pixel module to the DAQ system. The HDI will in turn be attached to a pixel interconnect flex cable (PIFC). All of these individual components will be tested before assembly. Once assembled, the pixel modules will undergo initial functionality tests followed by burn-in testing. The modules that pass the burn-in testing will then be mounted on a support substrate made out of thermal pyrolytic graphite (TPG) to form a pixel half-station. Next, all modules on a half-station will be fully tested for electrical and readout problems. Before assembly, each substrate will be tested for mechanical tolerances and thermal properties. A separate cooling test will be performed to insure that the pixel half-station achieves the designed operating temperature. During this process, all assembly and alignment parameters will be recorded in a database.

The pixel stations will next be mounted to a carbon fiber support shell to form a half-detector. During this step, the position of each pixel half-station will be aligned and the information will again be recorded in a database. Once the half-detector is fully assembled, each half-station will be tested and read out. This testing will be repeated after the half station is inserted into the vacuum vessel at SIDET.

When both half-detectors are inserted and all cables and connections inside the vacuum vessel are properly installed, connected, and tested, the vacuum vessel will be closed. Before transporting the vessel from SIDET to C0, a number of additional tests will be performed. These include:

- Vacuum test - the vessel will be pumped down to check for possible leaks
- Electrical test - the modules will be powered up to check for continuity
- Readout test - all modules on a half station will be readout simultaneously
- Actuator test - the half detectors will be moved closer and further apart and the read-back sensors calibrated.
- Cooling test - Leak tightness and temperature performance will be checked with the vessel under vacuum and the modules fully powered.

When the pixel detector has passed all these tests, it will be ready for installation.

13.12.10.2 Transportation of the Pixel Detector to C0

The following steps have to be made before transportation:

- The full pixel detector will be assembled, placed inside the vacuum vessel, and tested at SIDET;
- Temporary flanges will be used to cover the two ends of the vacuum vessel;
- Transportation fixture will be attached to the detector; and

- External cables will be connected to the detector and secured to the transportation fixture.

All pixel detector stations will be fully assembled and mounted to the half-detector support frame at SIDET. This will then be surveyed on a coordinate measuring machine (CMM) prior to insertion into the vacuum vessel. Fiducials will be placed on the vacuum vessel that can be used as reference points for the position of the pixel stations. All cables internal to the vacuum vessel will have been installed at this point. These include all the pixel interconnect flex cables and their connection to the feed through boards. The feed-through boards will be attached to the vacuum vessel. Actuators will also be attached to the pixel support frame and vacuum vessel and will be tested at SIDET. When the vessel is sealed, we will use the fiducials as reference points for the position of the pixel stations and modules. Hence, it is important that the pixel stations will not move during transport. The transportation will consist of the following steps:

- The detector will be transported from the SIDET assembly room to a loading area
- The detector will then be loaded onto the truck. A crane and trained operators will be required to lift the detector. A truck with an air suspended platform will be required. A detailed specification of the platform will be prepared in advance.
- The detector will be transported from SIDET to the C0 assembly building. The road condition will be inspected before the transportation. A security escort will be required to avoid unnecessary stops.

Equipment needed

To reduce loads and vibrations during transportation, an air-ride cart similar to the one used for the D0 silicon tracker will be designed and built. It will provide a stable platform for the pixel detector. The transportation fixture will include an integrated rail system that should be properly aligned to the support inside the magnet so that the vessel can be lifted and slid directly into position inside the magnet upon arrival at the experimental hall.

Special Handling

Once installed inside the vacuum vessel, access to the pixel stations will no longer be possible. The pixel stations will be precisely mounted using light-weight mounting brackets to the carbon support frame. The concern is that the detectors are very fragile and any mechanical vibration during transportation may cause displacement of the pixel stations from their aligned position or even damage the pixel modules and/or the interconnections. Thus extreme care must be taken during loading and the transportation of the pixel detector.

Personnel Required

- Physicists (including postdocs and graduate students): 3
- Electrical/electronics engineers: 1
- Mechanical engineers: 2
- Technicians: 4
- Rigging crew: 3
- Shipping crew: 3
- Safety personnel; 2

At least two technicians will be required to load and unload the detector to and from the truck. A trained crane operator will be needed. If a forklift is needed for detector loading, then a trained forklift operator will be required. Two experienced transportation crew will be required to control detector condition during the transportation. During the transport, they will stay in the truck close to the detector.

Time Required

The preparations, checks and final instruction of the personnel involved in the transportation will require 2 hours. Loading and unloading the detector to and from the truck will require about 1 hour each. The transportation and maneuvering will require 1 to 2 hours.

13.12.10.3 Installation of the Pixel Detector at C0

Installation Steps

The installation will proceed as follows:

- The detector will be unloaded from the truck onto the C0 assembly hall loading dock and moved to the assembly hall floor using the assembly hall crane. A trained crane operator will be required.
- The detector will be transported from the assembly hall to the experimental hall and prepared for insertion into the SM-3 magnet.
- Using a transportation fixture, the detector will be lifted and attached to overhead rails attached to the magnet. Note that the same rails may be used for the installation of the 1st, 2nd and 3rd straw stations.

- The detector will be rolled into the magnet, attached to the support brackets, and then disconnected from the rails. Details of this operation will be defined later, when a more detailed detector design will be available. The brackets will be installed and tested before detector installation.
- Using support brackets, the pixel detector will be finally aligned and secured. Surveyors will be needed. It is expected that the precision of the final alignment of the vessel fiducials will be better than 100 microns.
- The detector cables will be rerouted from the transportation fixture to their final positions, attached to the supports on the SM-3 magnet, connected to power supplies, data combiner boards etc sitting in electronics racks.
- The external cooling, vacuum, actuator lines, and power lines will be attached and tested. Some lines will be installed and tested before the detector installation.
- The temporary flanges will be dismounted and the end windows will be mounted in their places and connected to the rest of the beam pipe.

In addition to the above steps, it is envisaged that the power supply systems (both low and high voltages), power cables, cooling system, vacuum system, actuator lines, electronics racks (including power and cooling), data combiner boards, and monitoring cables will need to be tested and installed separately and beforehand.

- As can be seen from above, power supplies (both HV and LV) and power cables will be installed separately. The HV will likely be installed in the catwalk that will be located just outside the experimental hall. The LV power supplies could be located inside the experimental hall, near the walls of the enclosure. Similarly, four racks will be installed inside the experimental hall at the four corners of the SM-3 magnet to house the pixel data combiner boards. A power distribution system will be developed, installed, and tested before the pixel system is installed.
- The cooling system will be installed separately outside the experimental hall. The long cooling transfer lines will be insulated. The system and the transfer lines will be tested before connection to the pixel system.
- Due to space constraints, the vacuum pumps will likely be placed at some short distance (about 15 feet) away from the vessel, outside the magnet. The pumps and their controls will be installed and tested before connecting to the vessel after installation.
- The positioning actuators will probably be pneumatically driven. The required gas lines and the position control and monitoring system will be installed and tested separately.

Equipment Required

Due to the lack of an overhead crane in C0 experimental hall lifting devices will be required during the detector installation. The device capacities and specifications will be defined later when a more detailed detector design will be available.

C0 Infrastructure Required

Chilled water, dry nitrogen, clean and dirty power and temperature controls are required at C0. In order to test the pixel data combiner boards, we need cooling water (the racks will be water-cooled). We will need fast fiber-based Ethernet connections in order to properly check out the system. A crane will be needed at the assembly hall to unload the pixel vessel. Temporary scaffolding around the magnet will be required for the detector installation, redressing and connecting the cables, installation and connecting the cooling, vacuum etc. detector subsystems. The scaffolding may be used later for the straw station installation. Some portion of the scaffolding may be permanently installed to provide quick access to the detector subsystems located on the top of the magnet.

Potential Impact on other Level 2 subproject elements

The pixel detector will be rolled in from the uninstrumented side of the spectrometer. However, the first 2 forward tracking stations can only be installed after installation of the pixel detector has been completed.

Accelerator Impact of the Pixel Installation

During installation of the pixel detector, a section of the beam pipe that runs through the dipole magnet will be disconnected. It will be replaced by the pixel vacuum vessel and the dome shaped exit window. Appropriate stands must be provided to support the remainder of the beam pipe outside the dipole magnet.

Safety Issues

Job hazard analyses and safety documentation will be made for the detector transport process from SIDET to C0 and also for the installation process. Step-by-step transportation and installation procedures will be developed by BTeV and will be reviewed and approved by the PPD management before proceeding. Since this is an expensive and fragile system, we propose that a dry run be conducted before the real detector installation. A full-scale detector mock-up will be built for this purpose. We the cost of this (material and labor) should be included in WBS 1.10. It is possible that we will use the actual pixel vacuum vessel loaded with mock-up detectors for the dry run.

Personnel Required

- Physicists (including postdocs and graduate students): at least 10
- Electrical/electronics engineers: 2
- Mechanical engineers: 3
- Technicians: 6
- Rigging crew: 3
- Surveying crew: 2
- Safety personnel; 1

At least three technicians will be required to carry out the detector lifting, insertion and connection to the magnet. Up to four technicians will be needed to redress the cables and attach them to the magnet. The same technicians will work on other feeding line installation and checkout for the pixel detector system. Up to four electricians or electrical engineers will work on connecting the cables to the electronics racks and their subsequent testing. The exact number of people required will depend on the schedule and availability of the needed personnel.

Time Required

We estimate that the first two steps as described in this section above will take about one 8 hour shift, steps 3-6 another shift, and steps 7 and 8 will take 3 to 5 days depending on the test we would like to do, problems that we may run into and so on. Installation of the power supplies, cables, cooling lines, vacuum connections etc at C0 will take about 3 weeks.

13.12.10.4 Infrastructure Tests

This section describes the installation and tests of power supplies and cables, connection of the power supplies, data combiner boards, pixel data cables, timing and control cables, vacuum connections, actuator connections, cooling lines, and various control-line connections. After the connection of all cables and lines, all components of the system will be tested for continuity. Connections to and from the central Control, Timing and Monitoring (CT/M) system to the pixel data combiner boards (PDCB) will be tested. These tests will include the functioning of the clock into the data combiner board, which in turn will send the clock signals to all the pixel modules. This clock signal will be tested for synchronization at various clock speeds. Other pixel sub-systems such as the vacuum system, vacuum monitoring gauges, temperature control sensors, position control systems, and the cooling system will be tested for functionalities. The slow control and monitoring interfaces as well as the alarm/interlock interfaces of the various systems to the overall BTeV control/monitoring system and alarm/interlock system will be tested. The data combiner boards will be read out by either a preliminary test system (which will be used during the production phase of the PDCB) or the full DAQ.

13.12.11 RICH

This section describes the installation of the RICH detector into the C0 collision hall. The alignment of the detector elements in the overall C0 alignment system is described in the commissioning section.

13.12.11.1 Summary of Testing Prior to Moving to C0

Individual electronic assemblies are tested prior to moving to C0. The mirror arrays are pre-aligned at a Fermilab facility prior to moving to C0.

13.12.11.2 Transportation to C0 and Assembly of RICH Subproject Elements

Tank Frame Segments

The Rich Tank frame segments are shipped in pieces small enough to fit through the C0 exterior entrance door. The entrance door is approximately 12 feet wide and 13 feet tall. The frame segments are large and require a rigging crew and a technician crew to assemble. Assembly of the tank frame in the C0 assembly hall is estimated to take 1 month calendar time. The frame segments can be shipped on a flatbed truck.

Liquid Radiator Vessel

The liquid radiator vessel is inserted and mounted to the tank frame after the frame is assembled. Plumbing lines from the radiator vessel to the exterior of the tank are connected. Fiducials located on the radiator vessel are transferred to the tank frame. Mounting the liquid radiator vessel is estimated to take one week calendar time. Surveying time is estimated at one week calendar time. The liquid radiator vessel is fragile and should be transported carefully to prevent the quartz window from being damaged.

Windows

The RICH tank walls consist of acrylic windows and carbon fiber windows for photon and particle transparency. In order to make the windows replaceable, the windows are mounted with flanges and o-ring seals. Due to the large number of attaching bolts and the length of the o-rings, an initial gas leak check on all seals must be performed. Mounting the windows and leak checking is estimated to take 2 weeks calendar time. All windows can be transported on a flatbed truck. The rear window will have to be moved through the C0 entrance door separately and at an angle in order to fit through the door.

Beam Pipe

Installation of the beam pipe involves replacing the standard Tevatron beam pipe with custom beam pipe sections. The RICH beam pipe section is supported by the RICH tank frame. Then the window to beam pipe seal is made. Inserting the beam pipe into the tank frame and making the seals is estimated to take 1 week calendar time. The Vacuum joint is made after the tank has been installed into the C0 collision hall. Whenever handling Beryllium, the people involved should have the necessary training to handle Beryllium. Also a Job Hazard Analysis should be performed prior to any handling of the beam pipe.

13.12.11.3 Installing RICH Subproject Elements in the C0 Collision Hall

The RICH Tank

Once the RICH tank has been assembled with frame segments, windows, liquid radiator, beam pipe, and has been preliminarily leak checked, it is rolled into the C0 collision hall. The Tank is installed after the Vertex Magnet and the Toroid Magnets. The Tank must be installed prior to the Straw Tubes and the Calorimeter. The RICH tank installation involves the following steps:

1. The shielding door is opened at the start of a Tevatron shutdown period.
2. The RICH tank assembly is rolled into the collision hall by riggers utilizing rollers at C0 and temporary steel plates on the floor.
3. The beam pipe connections are made. The continuity of the Tevatron beam pipe must be restored to a vacuum below 10–7 torr.
4. The RICH tank assembly will be surveyed and adjusted to its correct location with respect to the Tevatron.
5. Gas connections to the C0 infrastructure are made.

Whenever handling the Beryllium beam pipe, the people involved should have the necessary Beryllium handling training. Also a Job Hazard Analysis should be performed prior to any handling of the beam pipe. It is estimated that installation requires 1 month and surveying requires 1 week of calendar time.

HPD Bee-Hive and Enclosure

The HPD array installation is performed after the Straw Tube installation is complete. The HPD array includes the mu-metal bee-hive, HPD enclosure, exterior magnetic shielding, The HPD hexads and associated electronics are independent to the assembly structure and can be installed when received. Installation of the assembly involves the following steps:

1. The large C0 shielding door is opened at the start of a Tevatron shutdown period.
2. The HPD enclosure is rolled into the collision hall by riggers utilizing rollers at C0 and temporary steel plates on the floor.
3. The HPD enclosure will be surveyed and adjusted to its correct location with respect to the Tevatron and the RICH tank.
4. All necessary electronic cooling, electronic readout, and gas purge connections are made to the C0 infrastructure.

It is estimated that installation requires 1/2 week per array and surveying requires 1 week of calendar time.

a) HPD Hexads

An individual HPD hexad can be installed by carrying it through the labyrinth door during a Tevatron shutdown period. Installation requires the removal of the exterior magnetic shielding on the HPD enclosure, opening the HPD enclosure, inserting the hexad into the bee-hive structure, making the necessary electronic and cooling connections, closing the HPD enclosure and replacing the exterior magnetic shielding. Installation of the hexad requires 1 day of calendar time.

PMT Bee-Hive and Enclosure

The PMT array installation is performed at a convenient time in the installation schedule and is not affected by the installation of other components. The PMT array includes the metal beehive, PMT enclosure, exterior magnetic shielding, PMT modules and associated electronics cooling and electronic cables. The PMT modules are independent to the assembly structure and can be installed when received. Installation of the assembly involves the following steps:

1. The labyrinth door is opened at the start of a Tevatron shutdown period.
2. The PMT assembly is rolled into the collision hall by riggers utilizing rollers at C0 and temporary steel plates on the floor.
3. The PMT assembly will be surveyed and adjusted to its correct location with respect to the Tevatron, the RICH tank, and the liquid radiator vessel.
4. All necessary electronic cooling, electronic readout, and gas purge connections are made.

It is estimated that installation requires 1/2 week per array and surveying requires 1 week of calendar time.

a) PMT Modules

The PMT modules are independent to the assembly structure and can be installed when received. The module can be installed using the labyrinth door. Installing the module into the PMT array requires access to the array location, inserting the module into the array, and making the necessary electronic and cooling connections. Installation of a module requires 1 day of calendar time

Mirror Arrays

The mirror panel consists of the individual mirror tiles, three point mounts used to attach the mirror tile to the mirror support panel, and mounts used to attach the support panel to the frame. As part of the mirror panel assembly, individual mirror tiles are calibrated and adjusted to each other prior to the mirror panel installation. The mirror panel installation involves the following steps:

1. The shielding door is opened at the start of a Tevatron shutdown period;
2. The mirror panel and its temporary support frame are rolled into the collision hall;
3. The RICH tank is opened by removing a side panel;
4. The Beam Pipe is separated to allow the mirror installation;
5. The mirror panel is transferred from the temporary support frame to the RICH tank mirror support rails;
6. The mirror panel is moved into position in the tank;
7. Fiducial marks on the mirror panel are transferred from the panel to the exterior of the RICH tank;
8. The Beam Pipe is reassembled;

9. The mirror panels are surveyed and adjusted to their correct location with respect to the Tevatron, the HPD arrays and the RICH tank frame.
10. The RICH tank is closed;

The mirror panels can be adjusted remotely by using motorized mounts. If an individual mirror tile needs to be replaced or adjusted, the rear window will need to be removed. Each time the beam pipe is separated, the continuity of the Tevatron beam pipe must be restored with a vacuum below 10-7 torr. It is estimated that the installation of the mirror panels requires 1 month and surveying requires 1 week of calendar time.

Filling The Liquid Radiator Vessel With C5F12 Liquid

Filling the liquid radiator vessel requires that the following tasks are complete:

1. The vessel has been installed into the RICH tank;
2. The RICH detector tank has been installed in the collision hall;
3. The vessel has been leak checked;
4. The liquid radiator re-circulation system is complete and has been tested.

The process of filling the liquid radiator vessel and confirming the re-circulation system is operating properly is estimated at 2 weeks of calendar time.

Filling The Rich Tank With C4F10 Gas

Filling the RICH radiator tank requires that the following tasks are complete:

1. The tank has been installed in the collision hall;
2. The tank has been leak checked;
3. All of the mirrors have been installed and are position with respect to each other, the HPD array, and the Tevatron;
4. The gas radiator re-circulation system is complete and has been tested.

The process of filling the RICH tank and confirming the re-circulation system is operating properly is estimated at 1 month of calendar time.

13.12.12 Counting Room - DAQ and Trigger

13.12.12.1 Readout and Controls

This section describes the Installation Plans for the Readout and Controls system.

Summary of Testing Prior to Moving to C0

The entire readout chain will be tested before moving to C0. These tests include front end modules (provided by the detector groups), Data Combiner boards, optical links and the L1 Buffer system. Integration tests will be performed for the Data Combiner - Front End module interface(s), the interface between the L1 Buffer system and the trigger system as well as for the interface between the timing systems and the detector electronics. Included in those tests is not only the hardware but also the software integration of the central run control and configuration systems, user applications and detector component specific components.

Transportation of Readout and Controls Equipment to C0

a) Equipment Required

All readout and controls equipment will be staged at the Fermilab Computer Lab and at the Ohio State University. Equipment will be moved from the Feynman Center to C0 by Fermilab Material Distribution Department Trucks and Drivers. The Ohio State University's motor pool will be used to move equipment from Ohio to Fermilab.

b) Special Handling

Relay Racks will be transported with standard tie-down precautions. Standard precautions (e.g. avoidance of electro static discharges) will be required for the transport of electronics modules. A transportation procedure will be prepared for the transportation operation.

c) Personnel Required

Most of the readout and controls equipment can be maneuvered by hand. The relay racks might require the use of a crane and other equipment to bring them to the first floor of the counting room.

d) Time Required

All relay racks can be loaded and transported in one-half day. Another one-half day will be needed for the transportation of the electronics modules, PC's and other equipment. Transportation of equipment from Ohio State will require two days.

Installation of DAQ Subproject Elements at C0

a) Installation Steps

Components of the readout and controls system will be placed in the C0 detector hall, the counting room and in the control room (both of which are in the C0 building). Installation of most of the readout and electronics components in the detector hall will be coordinated with the detector sub-groups. As soon as space becomes available, *i.e.* is no longer needed for the insertion of detector components, we will install the racks that house the DCBs and the optical switch modules (Note: the exact placement of the DCBs is still under discussion. Some might be located in the detector hall while others will be in the counting room. In the latter case optical switch modules will be used in the detector hall. For each component cables need to be installed to connect the front end modules to the DCB/Optical Switch box - about 3,000 cables in total. The connection to the counting room is provided by approximately 256 optical fiber bundles (each with 12 fibers). Before we can run these bundles we will install special inner-ducts in the ducts connecting the detector hall with the counting room. This way we will be able to replace individual fibers should a problem develop. Approximately 300 cables will connect each DCB/Optical Box with the timing system. An installation plan for the readout and controls cabling will be developed in coordination with the detector groups and the overall installation coordinator (wbs 1.10).

Installation of readout and controls equipment in the counting room starts with the relay racks, power and cooling. Once these services are available we will install the L1 Buffer system and the Data Combiner modules that are not located in the detector hall. Approximately 3,000 network cables have to be installed between the L1 Buffer system, the switching network and the Level 2/3 farm. Work in the control room can proceed in parallel. Installations steps include setting up the control room furniture, the network infrastructure as well as the computer/operator consoles. Just as the readout system the detector control system requires equipment to be installed in different location. Most of the monitoring and control system in the detector hall will be installed by the sub-detector groups. Network (Cat 5) and field-bus cables will connect these systems to the supervisor components of the control system that are located in the counting room. The precise location of the equipment computer (Detector Manager and Control Manager/Supervisor) still needs to be defined. While most of these workstations will be placed in the counting room some need to be close to the hardware and will reside in the detector hall. The elements of the Global Detector Control System will be split between the counting room (supervisor CPUs) and the control room (workstations with the user interface(s)). Installation of the detector control will be coordinated with the detector group and the installation coordinator (wbs 1.10). An installation plan will be developed.

b) Equipment Required

No special installation equipment is required. A crane might be needed to lower (some of) the relay racks into position.

c) Special Handling Issues

Electronic modules have to be handled with care to avoid damage due to electrostatic discharge.

d) C0 Infrastructure Required

Utilities required at C0: electrical power, water cooling for the relay racks, network connection.

e) Potential Impact on Other Level 2 Subproject Elements

For a system test each component needs to have at least parts of the readout and controls equipment in place. However, care must be taken to avoid that these modules and cables block access to the detector and impede the installation of other components. A detailed cabling schedule will be developed.

f) Accelerator Impact of Installation

None - of course we need access to work in the detector hall.

g) Safety Issues

None (besides standard work place safety)

h) Personnel Required

Riggers for the relay racks, furniture. Electricians, plumbers for the electric and cooling infrastructure (relay racks).

i) Time Required

First estimate (actual time for the job):

Install 3000 readout cables (front end - DCB/Optical box)	1000 hours
Install 256 optical fiber bundles	300 hours
Install 3000 network cables	500 hours
Install 300 timing cables	150 hours
Install 22 relay racks, connect to services	100 hours
Install 240 DCB modules	10 hours
Install 320 L1B modules	10 hours
Install detector control cables	150 hours
Install PCs and workstations (50)	100 hours

13.12.12.2 Trigger Electronics and Software

The trigger system will be developed in a three-step process of prototype, pilot, and production hardware. The prototype and pilot hardware will not be used at C0, so details of the testing of those components are not included in this document. The production hardware will be tested using a three-step process before the hardware is integrated at C0. Once the hardware is located at C0, we envision that integration of the trigger system with the DAQ and BTeV detectors will be the primary focus of our effort. This means that we will concentrate on any remaining system issues at C0, since individual modules and trigger subsystems will have undergone previous testing.

Summary of Testing Prior to Moving to C0

The three steps of production hardware testing are individual module tests, module interconnections tests, and system integration tests. These tests will be done on all modules before they can become part of the system at C0. The initial testing will be done at other appropriate sites at Fermilab or, in the case of the Muon trigger, Fermilab and/or UIUC. Since the muon trigger will utilize a considerable amount of hardware identical to the pixel trigger, it is advantageous to plan a test stand for the muon trigger at Fermilab, adjacent to the pixel trigger. If the muon trigger development is staged through this test stand at Fermilab (prior to moving to C0), then all of the following sections addressing transport, installation, and testing will apply equally to the pixel and muon triggers.

Transportation of Trigger Subproject Elements to C0

a) Equipment Required

The trigger hardware will either be packaged in electronic sub-racks or packed in boxes as individual modules. Movement to C0 can be done with most sizes of trucks and/or personal vehicles. If equipment is coming from UIUC, it will be packaged more completely because of the longer and rougher transportation required.

b) Special Handling

The vehicle transporting the trigger modules and sub-racks to C0 should have a functioning suspension that minimizes bumps and acceleration forces on the modules. Air-ride trucks could be used for UIUC equipment.

c) Personnel Required

Vehicle driver.

d) Time Required

Less than an hour per Fermilab load depending on vehicle and loading. Less than a day per UIUC load. The entire trigger system could be moved to C0 in less than a week. If move of the L2/3 PC farm to C0 can be staged, i.e. C0 is ready with at least partial power and cooling, this will be adopted. In this case the move of the L2/3 PC farm will be in three stages to take place as each procured proportion of the farm is tested. This is because the procurement of 50% of the PC farms is expected to be in the last fiscal year, whereas we would want to start installation and integration at C0 before this last 50% shipment is completely tested and integrated.

Installation of Level 2 Subproject Elements at C0

a) Installation Steps

Empty electronic racks are first installed in the counting room. Then sub-racks are installed and then the trigger modules inserted. Cables are routed and connected and then system tests begin. Note that the L2/3 PC farm is planned to be installed in a counting room above the one where the L1 trigger is installed. Due to the procurement schedule for the L2/3 PC farm, where 50% of the farm is purchased in the last fiscal year, installation of the L2/3 PC farm will be staged. The initial 50% of the PC farm, after testing and subsystem integration will be moved to C0 when the L2/3 counting room has the necessary power and cooling. Empty racks will be installed first and the rack mountable PC farm will then to put into the racks and cabled up. Like the initial 50% of the PC farm, the final 50% of the PC farm will be tested away from C0, however the subsystem integration of these at C0 can occur directly at C0.

b) Equipment Required

Possibly tools, cable, and connectors if cables are to be made up at installation time.

c) Special Handling Issues

There are no special handling issues with the equipment.

d) C0 Infrastructure Required

C0 utilities required are normal quiet AC electrical power and cooling, either chilled water or room air conditioning. Network connections within and between the different trigger subsystems are required and the necessary networking for this needs to be available, e.g. between the different counting rooms. Full networking will be required to integrate with the DAQ and data archival systems and to test and integrate offline related software in the L2/3 PC farm. Note that sufficient power and outlets are required in the L2/3 Trigger counting room. (E.g. FCC is starting to get to its power limit.) We need the appropriate split in power and power density to the counting rooms (see the counting room document.)

e) Potential Impact on Other Level 2 Subproject Elements

The run control computer should be able to emulate the trigger system both before installation and while the system is under repair. We assume that C0 will have sufficient power and cooling so that startup and operation of the trigger system will not impact other subproject elements in terms of power or cooling needs.

f) Accelerator Impact of Installation

Trigger installation has no impact on the accelerator or other beam line components.

g) Safety Issues

Trigger system installation will involve the safety issue of electrical power. ES&H reviews of the general installation procedures will be completed before the work begins and the trigger hardware will be part of those reviews. The trigger system may also involve the safety issue of moderate to heavy weights depending on the granularity of installation.

h) Personnel Required

The trigger electronics will be installed in the counting rooms. The rooms will be assumed to have under-floor power wiring and operating cooling systems. No special crews are needed for trigger installation if the electrical and cooling systems are functional.

i) Time Required

The L1 trigger subracks and modules can be installed in less than two weeks if electrical power and cooling are available in the counting room. Installation and testing of the interconnection cables will take twice four weeks with one week of overlap with the installation. Installation of the initial 50% of the L2/3 PC farm will take two weeks and can proceed in parallel to the L1 trigger installation since the two systems are installed in different counting rooms. The integration and testing of the L2/3 trigger subsystem will take a further 4 weeks.

13.12.13 Electronics

The installation of electronics racks in the counting rooms is independent of the operations in the Assembly Hall except for some minimal interference in the loading area. The electronics racks that will be installed in the Collision Hall will be fully tested in the Assembly Hall before they are rolled into the Collision Hall. All electronic and electrical systems will be inspected and certified to follow all applicable electrical and mechanical standards.

13.13 Integration

13.13.1 Toroids

After assembly in the C0 Assembly Hall, the muon toroids, with their embedded compensation dipole, will be temporarily connected to their power supplies (which also sit in the assembly hall). The magnetic field monitor, controls and safety connections will be installed on the toroids and compensating dipole. The magnetic fields will be extensively measured using the Ziptrack magnetic field measuring device.

After the muon toroid assembly is rolled into its final location in the C0 Collision Hall, the permanent power, control, and safety connections for the toroids and compensating dipole will be made. The remote operation, readout, and control of the toroids and compensating dipole and their safety systems will be checked. The ability of the current in the current in the compensating dipole to follow the MDAT ramp of the main Tevatron magnet excitation current will be verified.

After allowing at least two weeks for any potential settling of the collision hall floor, the muon toroid assembly will be shimmed into its exact final location with respect to the primary Tevatron tunnel survey monuments. The compensating dipole will then be adjusted with respect to the toroids so that it is precisely aligned with the Tevatron beamline. Secondary fiducial marks will be mounted on the toroids and compensating dipole to facilitate continued monitoring of the survey location of these elements, and the BTeV spectrometer muon detectors, during the lifetime of the BTeV spectrometer.

13.13.2 Vertex Magnet

After assembly in the C0 Assembly Hall, the vertex magnet will be temporarily connected to its power supply (which also sits in the assembly hall). The magnetic field monitor, controls and safety connections will be installed on the magnet. The magnetic field will be extensively measured using the Ziptrack magnetic field measuring device.

After the vertex magnet is rolled into its final location in the C0 Collision Hall, the permanent power, control, and safety connections will be made. The remote operation, readout, and control of the magnet and its safety systems will be checked. The ability of the current in the magnet to follow the MDAT ramp of the main Tevatron magnet excitation current will be verified.

After allowing at least two weeks for any potential settling of the collision hall floor, the magnet will be shimmed into its exact final location with respect to the primary Tevatron tunnel survey monuments. Secondary fiducial marks will be mounted on the walls and floor of the collision hall and on the magnet to facilitate continued monitoring of the survey location of the magnet, and BTeV spectrometer detector elements, during the lifetime of the BTeV spectrometer.

13.13.3 Muon Chambers

The muon chambers will be connected to their gas supply. The gas monitoring system will be installed tested and certified. The readout electronics racks will be installed and cabled to the detectors and to the upstairs counting room receivers. When the system is fully assembled, muons from horizontal cosmic rays and from Tevatron backgrounds during normal operations will be tracked through the full muon detector. The successful observation of such tracks will mark the commissioning of the muon detector system.

Mechanical: As each wheel is installed, the gas system will be tested for leaks and proper flow. When wheels are mounted, we will perform a rough survey of the wheel location.

Electrical/electronics: As each octant is installed and connected, we will (carefully) bring them up to voltage and verify that they are drawing the expected current. We will check a channel or two in each plank with a scope to verify that they seem to be behaving as expected (expected noise level, signals look OK, etc.). We will then readout each channel and verify that each is connected to the DAQ and functioning as expected.

Personnel required: Muon group (and muon trigger group) personnel can perform all stand alone testing, although some interaction with the DAQ and trigger groups will be important.

Time required: This activity will go on over an extended period of time (two years), as described above. This will give us plenty of time to debug our software and to perform multiple tests; we should not have a problem keeping up.

13.13.4 EMCAL

The full complement of crystals will be installed in the EMCAL detector. The readout electronics racks will be installed and cabled to the detectors and to the upstairs counting rooms. The climate control hut enclosing the crystals will be completed and tested. The light pulser calibration system will be installed and tested. The list of specific integration items is shown below:

- The interlock system for power with cooling system will be tested and verified.
- The oxygen depletion sensor if dry nitrogen is used.
- The electronics associated with an individual crate will be tested without an external clock. Two or more crates will require a common clock that can be provided by the experiment-wide clock distribution system (if available) or by our distributing our own clock for testing purposes.
- Second check for mechanical tolerances.
- The support structure will be surveyed and aligned to within 1mm.
- The environmental control system will be tested for proper temperature and humidity regulation.
- The electronics in an individual crate will be tested independently.
- PMTs and bases will be tested with a crate as the calibration system becomes available.
- Multiple crates/PMTs/bases can be tested when the calibration system and the PC DAQ system (or a slice of the full DAQ system) is available.
- Once DAQ becomes available, EMCAL part of data-taking software will be completed.

Personnel Required

Technicians, students and physicists.

Time Required

It will take three years. Mainly since crystals will become available a few at a time throughout the entire construction period, and testing will be done as crystals are installed.

13.13.5 Beam Pipes

After the final installation of the thin-walled beam pipes, the full complement of vacuum pumps and vacuum readout and controls will be installed, tested and certified by the Beams Division vacuum group. The beam pipe has very small clearance from the circulating Tevatron beam; it must be surveyed before the Tevatron can return to normal running. The vacuum in the Tevatron must be 10^{-8} Torr or better. After the vacuum level has been accepted by the Tevatron Group in the beams Division and after beam has been successfully circulated in the Tevatron, the beam pipe will be declared fully commissioned.

13.13.6 Straw Tracker

After installation the following integration tests will be done:

- Leak test gas and cooling water systems.
- Test temperature and humidity monitoring and check that power supplies are shut off in the event of a cooling failure, or if humidity is too high.
- Test gas monitoring systems (gas gain, drift velocity, contaminant level), check functionality and integrate into slow control system and database.
- Check that all modules hold HV.
- Threshold voltages and other programmable registers will be set and read back
- Test Front-end electronics with pulses injected at pre-amp inputs
- Test readout into Data Combiner boards

Personnel Required

Technicians, Fermilab ES&H, students and physicists.

Time Required

This can be an on-going process and much work can be done in parallel with installation. In total, several months will be required.

13.13.7 Silicon Forward Tracker

13.13.7.1 Testing at C0

During the station assembly we plan to execute only some tests to check for the continuity of all the connections; cooling lines, in particular, have to be leak checked and pressure tested. Once the station is completely installed and sealed inside its enclosure, it can be turned on and run. Cooling circuit parameters, such as flows and temperatures, will be continuously monitored while the system is approaching its stationary regime. An extensive check of all the functionality and performance of the station detectors will be carried out by electrically pulsing the FE chips and reading it out through the final DAQ system. Particular care will be devoted to establish a clean grounding of the system. Once the station is fully checked, it will be ready for the final positioning. The station will be smoothly rolled into the final position together with the straw chambers. A final survey of all the fiducials on the station support will be done before to declare the station *installed & operational*.

Stand-Alone Subsystem Testing: The station will be tested as a stand-alone subsystem by electrically pulsing the FE chips. The major requirements to carry out this test are described in the following subsections.

– **Mechanical:**

  We will take care of the installation, debugging and running of all the cooling system needed for micro-strip stations. We will prepare it well before the installation of the first station. We require that the external water circuits to dump the heat of the main chiller units, be installed and operational. Piping from the remote chiller units to the distribution panels in the experimental hall should be installed and leak and pressure checked. Obviously, the mechanical structure to roll both the micro-strip and straw stations into the final position, should be ready and calibrated.

– **Electrical/Electronics:**

  The final quiet AC mains should be installed and tested. The power supply systems should be operational both for high and low voltages. The Data Combiner Boards should be installed and fully checked for read out. The final bunch crossing clock should be available, or at least a fake one should be generated. All the alarms and monitors should be in place and operational (readable).

– **Software:**

  The final DAQ should be ready and operational, or at least a part of that, which would allow us to read out the system trough our Data Combiner Boards. It should accept and process in `OR` mode a variety of calibration triggers synchronized with the main bunch crossing frequency. Event builders should be ready for each subsystem. We will take care of all the specific software development to test and calibrate our system.

- **Personnel Required:**

  The micro-strip group will take care of all these stand-alone tests. In addition, we need the assistance of a DAQ expert and a monitor/control expert for the duration of these tests.

- **Time Required:**

  We plan to execute all these tests on each stations in about four days.

13.13.8 Gas Systems

The Fermilab PPD Department has an established procedure and committee for checking the mechanical and electrical safety of experiment gas distribution systems. After the system has been fully assembled, connected to all monitors and controls and been certified by the Gas Safety Committee, the gas system will be fully commissioned.

13.13.9 High Voltage Systems

As high voltage mainframes are installed for detector systems:

- interlocks are verified
- hardware and software limits are set
- channels are matched to the software and proper software limits, alarms and warnings are installed and functioning
- cables are attached and verified
- the detector can now be hooked up

13.13.10 Pixel Detector

13.13.10.1 Multiple Subsystem Testing

Test with L1 Trigger processor and DAQ system

The multiple subsystem tests fall roughly into the following categories:

- Pixel readout/DAQ integration
  - Timing and control link tests

    - * Data link test
  - DAQ/Slow control integration tests
    - * Control/monitoring
    - * Data link tests
  - Pixel Readout/Trigger integration tests
    - * Data link test

Safety Interlocks

1. Power supply system interlocks
   The design of the low and high voltage distribution system will follow established ES&H practices at Fermilab. The low voltage distribution will be designed to minimize the risk of short circuits. This will be accomplished by each power supply having over voltage and over current protections and trips set at appropriate levels. Interlocks between temperature sensors on the pixel stations and the support structure will shut off power supplies in the event of a failure of cooling to a part of the detector. These interlock actions will be independent of the normal pathways for data logging and will be fully tested during the integration and testing phase.
2. Interlocks with the beam vacuum
3. Interlocks with the dipole magnet
4. Interlocks with cooling system
5. Interlocks with radiation monitor

Software

Online software developed for the Pixel system, including GUI, software for control/monitoring; database etc will be integrated with the global BTeV online software and databases.

Personnel Required

- Physicists (including postdocs and graduate students): at least 10
- Electrical/electronics engineers: at least 2
- Mechanical engineers: 1
- Technicians: 1
- Computing professionals: 2

Time Required

Experience from other Tevatron collider experiments show that these steps may take 6 months or longer depending on what problems are encountered.

13.13.11 Counting Room - DAQ and Trigger

13.13.11.1 Multiple Subsystem Testing for DAQ

Mechanical

None.

Electrical/Electronics

Repeat internal test program developed previously using the Integration Test Facility including tests of the entire readout chain and the detector control system.

Software

Repeat internal test program developed previously using the Integration Test Facility including tests of the entire readout chain and the detector control system.

Personnel Required

Time Required

13.13.11.2 Multiple Subsystem Testing for the Trigger

The trigger system gets input from the pixel detector, muon detector, timing/clock system and some detector system trigger primitives. All of these inputs will be emulated until the associated hardware can produce the required data. As these data streams are developed, they can be applied to the trigger system for testing and integration. The trigger system sends output to the DAQ, offline data logging, and the experiment run control system. Testing of the trigger system does not require any of these systems, and as they are developed, the trigger system can connect to them for testing and integration. This section applies to testing and integration of trigger subsystems with non-trigger systems.

Mechanical

See the Mechanical section in the Trigger commissioning section below.

Electrical/Electronics

See the Electrical/Electronics section in the Trigger commissioning section below.

Software

See the Software section in the Trigger commissioning section below.

Personnel Required

See the Personnel Required section in the Trigger commissioning section below.

Time Required

The vertical slice hardware initially installed at C0 will be capable of connecting to and testing an equivalent slice of the associated detectors and experiment systems. This can happen in a one to two month time scale after the trigger hardware is functioning stand-alone. Expansion to the full trigger system with all of it's interconnects should take six to eight months if all the hardware is available at the start of the integration.

13.14 Commissioning

13.14.1 Toroids

After the remote operation, readout, and control of the magnet and its safety systems is verified, the ability of the current in the magnet to follow the MDAT ramp of the main Tevatron magnet excitation current is verified, and the toroids have been shimmed to its final position, the commissioning of the toroids is completed.

13.14.2 Vertex Magnet

After the remote operation, readout, and control of the magnet and its safety systems is verified, the ability of the current in the magnet to follow the MDAT ramp of the main Tevatron magnet excitation current is verified, and the toroids have been shimmed to its final position, the commissioning of the toroids is completed.

13.14.3 Muon System

We describe the testing and commissioning of the muon system at C0.

13.14.3.1 Stand-alone subsystem testing

Mechanical: As each station is completely installed, the gas system will be tested for leaks and proper flow. We will also have the station surveyed and perform final alignments.

Electrical/electronics: As each station is installed and connected, we will (carefully) bring them up to voltage and verify that they are drawing the expected current as measured previously during the integration of the octants. We will then readout each channel and verify that each is connected to the DAQ and functioning as expected.

Software: We will look for cosmic rays and at beam background from spray when the accelerator is on. This will allow us to debug our readout software, reconstruction software, and the muon trigger before beam arrives.

Personnel required: Muon group (and muon trigger group) personnel can perform all stand alone testing, although some interaction with the DAQ and trigger groups will be important.

Time required: This activity will go on over an extended period of time (two years), as described above. This will give us plenty of time to debug our software and to perform multiple tests; we should not have a problem keeping up.

13.14.3.2 Combined systems testing

Electrical/electronics/readout/software: We hope to be using the DAQ early on, even in our "stand alone" tests. We also hope to use these tests to debug the muon trigger. So, the above "stand alone" tests will also be integration tests with the DAQ and trigger, two important elements that we connect with. We also will want to investigate higher level triggering, which will require information from the tracking systems. Once the tracking systems become available, we will start these tests.

Personnel required: Muon group (and muon trigger group) personnel will participate. Some interaction with the DAQ, trigger, and tracking groups will be required.

Time required: This activity will go on over an extended period of time (two years), as described above. This will give us plenty of time to debug our software and to perform multiple tests; we should not have a problem keeping up.

13.14.3.3 Completion of commissioning

The muon detector will be considered fully commissioned when the entire system is under voltage, gas is flowing, and near-horizontal hits from cosmic rays or beam backgrounds are able to be read out through the DAQ.

13.14.4 EMCAL

The full complement of crystals are installed in the EMCAL detector. The readout electronics racks are installed and cabled to the detectors and to the upstairs counting rooms. The climate control hut enclosing the crystals is completed and tested. The light pulser calibration system is installed and tested. A calibration of the full array of crystals will be made using vertical cosmic rays and the pulser system. When this calibration is complete, the EMCAL detector will be fully commissioned The calibration is not expected to take more than a month.

13.14.5 Beam Pipes

The Beam pipes will be fully commissioned after passing all the vacuum and detector element checks.

13.14.6 Straw Tracker

After the silicon and straw tracker stations have been installed around the thin-walled beam pipe, the electronics readout racks can be installed and cabled to the detector and to the counting room upstairs. The straw and silicon tracker gas systems and gas monitors must be installed, checked and certified. When pulses injected into the preamp by the straw calibration system and/or horizontal cosmic rays can be observed, the forward tracker will be fully commissioned.

13.14.7 Silicon Forward Tracker

13.14.7.1 Multiple Subsystem Testing

As described above in integration, our *stand alone* tests will also be integration tests with the DAQ and other systems, such as the trigger and the monitor/control system. We will continue to refine this kind of test during all the micro-strip installation period.

- **Software:**
  We plan to refine and update our software as required by the debugging process.

– **Personnel Required:**
  Certainly the micro-strip group and the availability of the DAQ and trigger experts.
– **Time Required:**
  The duration of these multiple subsystem tests will last all the installation period which should be roughly one year at most.

13.14.8 Gas Systems

The Fermilab PPD Department has an established procedure and committee for checking the mechanical and electrical safety of experiment gas distribution systems. Commissioning plan for the gas system (in addition to the PPD plan):

– Verify flammable gas interlocks, shunting systems and exhaust system

– Leak check detector sub systems system

– Monitoring and control systems

  verify hardware limits limits (e.g. like a limit in a photohelic) in order to to test valves, solenoids and shunts

  vary automatic systems to verify that they operate according to design.

  verify that alternate gas systems (such as nitrogen) work according to design

  verify that specifications and limits are set properly and monitoring software and procedures are in place and working properly

  allow system to operate for several months before data taking begins.

13.14.9 High Voltage Systems

Before the High Voltage system is considered commissioned, all interlock systems must be verified, software and hardware limits be verified, and monitoring procedures be tested and functioning. It is useful to have the high voltage system commissioned and operating at least a month before the arrival of first beam so that problem channels and elements can be identified.

13.14.10 Pixel Detector

After installation, a full system check out of the detector will be made. This includes grounding and shielding tests, electrical tests, readout, actuator tests, vacuum, and cooling tests.

13.14.10.1 Stand-Alone Pixel system testing

System Electrical Test at C0

Once all power supplies and cables are in place, an initial electrical test will be made to insure that both HV and LV can be turned on for all of the pixel modules. The current will be monitored. A turn-on and turn-off sequence will be worked out in preparation for this test (during testing at SIDET). This test will also be useful to exercise the control/monitoring software and interface to the overall BTeV control and monitoring system. All voltage settings and read-back currents will be monitored and recorded in a database.

Pixel system readout test

All of the tests described so far, during assembly and before shipping to C0, are performed using stand alone PCI based test stands and prototype data combiner boards. These tests are aimed at testing the pixel modules extensively during each step of the assembly in order to detect problems and fix them. After installation at C0, the testing that needs to be done will be a test of the real readout chain that will be used for the data acquisition in the experiment. This test is described below. The tests will include the following steps:

- down-loading information and read-back data for all modules
- determining the optimal settings for all modules (threshold, kill pattern)
- sending a test pulse and reading back the resultant data

Electrical testing - Grounding and shielding

Given the great sensitivity of the front-end electronics in the pixel detector, it is essential that stray electrical noise be reduced to a virtually negligible level. All signals in the pixel detector will be transmitted via shielded twisted pair cables. It is also essential to avoid any ground loops that could cause stray current to flow near the sensitive front-end preamplifiers.

To avoid ground loops, BTeV will develop a grounding and shielding policy as outlined in the BTeV document on Digital Electronics Standards. The pixel detector will be isolated from the other subsystems including the forward trackers. Furthermore, all data, timing and control signals will be transmitted via low-level differential signals over shielded twisted pair cables. The cable shield at one end will be isolated from ground.

High modularity of power supplies (both LV and HV) will be used. For the LV, the power supply returns will be isolated from ground. For the HV, the return will be connected to ground at the power supply for safety reasons, but will be isolated from the pixel detector "reference ground" by suitably high impedance.

Electrical safety is addressed by following the Fermilab guidelines and the practices specified by the Fermilab electrical safety program (FESHM 5046).

Vacuum tests

After the pixel vacuum tank is connected to the rest of the beam pipe via the dome shaped exit window all pumping ports, flanges, gauges, and other monitoring connections will be made and leak checked. The vacuum system will then be turned on and left running. The vacuum reading will be monitored continuously. The vacuum must be maintained at a level close to 10^{-8} Torr in the beam region. With the system under vacuum, the pixel vessel will be surveyed with an accuracy of better than 100 microns with respect to the center of the Tevatron beam line. Readout tests of the pixel detector will also be performed to make sure that there is no degradation in performance of the detector. Finally, the remote operation, readout, control and alarm/interlock interface of the vacuum system by computer will be tested. Note that before the installation of the pixel detector, a vacuum failure mode analysis will be performed. Furthermore, a study on the responses of the alarm/interlock to vacuum failure will need to be checked.

Cooling system tests

The cooling system will most likely be installed outside the experimental hall and long insulated transfer lines will be used to convey the liquid nitrogen from the dewar and recycling system to the pixel detector. After installation, the system will be turned on. The temperature at the entry and exit point of the liquid nitrogen recycler will be monitored together with the pressure at a few places in the system (entry and exit points of the pixel detector vessel for example). The temperature at various pixel stations will also be monitored continuously. Adjustments will be made to achieve the required stability as specified in the Pixel Requirements Document. This is done by a combination of the flow rate and the temperature control system on each substrate. The remote operation, monitoring, alarm/interlock interface of the cooling system will then be tested. Any adverse effect on the performance of the detector and the vacuum system will also be checked and appropriate measures will be taken to solve any problems encountered. Finally, the position effects of power failures of individual and full pixel power supplies will also be studied.

Actuator Tests

The pixel detector will be moved out and into the data-taking position by a set of 8 actuators. The actuators will be tested extensively before installation. After installation, we will run tests to make sure all the connections (electrical and gas if needed) are intact. We will then exercise the movement a number of times to make sure that the detector can be moved out and into the right position. Furthermore, we will check various operational parameters to make sure that these will not be affected by the operation of the actuators. These parameters include the current seen in the detector, temperature of the detector, vacuum, magnetic field map, and the position of the detector. For position monitoring, we may use two different methods such as encoder, capacitive readout etc. These different methods will need to be cross-calibrated. For emergency and safety reasons, there will be a manual backup system (in case one ore more of the actuators fail in some way). This system will also be tested during the check out.

Detector Alignment

The position of the pixel detectors must be known to within 100 m in order for it to be ready for a quick alignment run before normal data taking. This precision is required at the end of the installation period to ensure proper track matching within the pixel detector system and between the pixel and the forward tracker. The mechanical support and assembly of the pixel system are designed to easily provide the required level of precision and stability. However, after installation, we cannot further access the pixel stations and so must rely on the presence of fiducial marks placed at various locations on the vacuum vessel. The task of the alignment is to measure and monitor the position of the fiducial marks relative to one another, to the Tevatron beam line, and to the forward tracker. The location of the pixel vacuum vessel inside the dipole magnet limits the types of alignment and monitoring techniques that can be used. We will learn from the experience of other experiments such as CDF, D0, and HERA-B.

Databases

The amount of information that we need to keep track of during the assembly of the BTeV pixel detector is large. This includes the various parameters from the large number of components that need to be tested, the assembly and alignment parameters, voltage and threshold settings, and monitoring information. Furthermore, there will be a number of vendors involved during the various stages of the assembly and we will need to keep track of the inventory of the parts at each step of the process. Finally, a number of institutes will participate in the testing of the components and we need to maintain a stringent and uniform quality control. For these reasons, we need a production and testing database to store all the information relevant to the production and testing.

During system integration and testing, we will need a database to keep track of all information pertinent to the performance of the detector. These include voltage and current settings and limits, gains, noise, threshold dispersion, operating temperature, vacuum settings, and alignment constants. This should be part of the same database that will be used throughout the run.

Software Requirements

Software is needed for testing, calibration, monitoring and readout of the pixel detector. Offline data analysis software will not be described here. The major components of the software that will be required for integration and testing are the database (described in the previous section), a graphical user interface (GUI) for run control and DAQ monitoring, and online software for calibration and detector monitoring. The GUI and online software will be used to initialize the readout chain, set the operational parameters of the pixel detector (HV, LV, threshold, masking of noisy pixels etc), record pulser events, display events, reset the detectors or the pixel data combiner boards, perform a status scan of the voltage, current and threshold settings and so on. They will also be used to monitor the voltage, current, temperature, pressure inside the vessel, radiation levels, and the position information of the detector. These will be extensively tested and debugged before the installation of the detector. During commissioning, a complete system of control and monitoring will be tested.

Personnel required

– Physicists (including postdocs and graduate students): 10 or more
– Electrical/electronics engineers: 2
– Mechanical engineers: at least 3
– Technicians: 4 or more
– Computing professionals: 1
– Survey crew: 2

For the vacuum tests, technicians who are familiar with vacuum and cryogenics system will install and test the vacuum system. When the entire pixel vacuum system is ready to be turned on and left running, engineers and technicians from the BTeV experiment and from the Tevatron will be on hand. The surveying and alignment group will survey align the pixel vessel. Physicists in the pixel group and engineers will monitor the readout of the detector. BTeV physicists, engineers and technicians will program and monitor the remote operation, readout, control, and computer alarm/interlock interface.

For the cooling system tests, technicians who are familiar with the BTeV cooling system will assemble the system and install the transfer cooling lines. BTeV engineers and technicians will test, monitor and adjust the pressure, temperature, and flow rate of the coolant through the installed system. They will also test and monitor the remote operation, readout, and computer alarm/interlock interface.

Time Required

Experience from other Tevatron collider experiments show that these steps may take 3 months or longer depending on what problems are encountered.

The total duration to install, test, and start up the vacuum systems is estimated to be three months. This includes a month and half for technicians to install the vacuum systems, a month for technicians to test and leak check the system, and a few days for the surveying group to record the alignment of the system. BTeV physicists and engineers and Tevatron engineers will probably spend two weeks monitoring the vacuum system when it is first turned on. BTeV physicists and engineers will spend another two weeks debugging and monitoring the readout of the detector. BTeV engineers and technicians will spend one month programming and monitoring the remote operation, readout, control, and computer alarm/interlock interface.

The total duration to install, test, and start up the cooling system is estimated to be three months. This includes one month for technicians to assemble the cooling lines, the insulated transfer lines and monitoring and control systems and one month for technicians to test the system. BTeV engineers and technicians will spend one week monitoring the pressure, temperature, and flow of the system when it is first turned on. They will also spend about three weeks programming and monitoring the remote operation, readout, and computer alarm/interlock interface.

13.14.11 RICH

After installation, a full system check will be made to bring the RICH subproject to an operational state. This includes the gas, power supply, cooling, electronics, DAQ software, control/monitoring, and alignment systems.

13.14.11.1 Infrastructure tests

After the connection of all cables and lines, all components of the system will be tested for continuity, Connections to and from the central Control, Timing and Monitoring (C&T/M) system to the RICH data combiner boards will be tested. These tests will include the functioning of the clock on the data combiner board, which in turn will send the clock signals to all the HPD and PMT modules. This clock signal will be tested for synchronization at various clock speeds. Other RICH sub-systems such as the vacuum system, temperature control sensor, cooling system will be tested for functionalities. The slow control and monitoring interfaces as well as the alarm/interlock interfaces of the various systems to the overall BTeV control/monitoring system and alarm interlock system will be tested. The data combiner boards will be read out by either a preliminary test system or the full DAQ.

13.14.11.2 Assemble and test of HV and LV systems

The HV and LV systems will be installed at the same time. The power supply crates will be installed in racks. The HV and LV cables will be checked for continuity while being connected. A safety document on HV operations will be written and a hazard analysis will be performed if necessary. Once all HV and LV supplies and cables are in place, an initial electrical test will be made to ensure that the HV and LV can be turned on for all HPD and PMT modules. The current and voltage values of each power supply channel will be monitored. A circuit to read-back the current and probably also the voltage will be included in the design of the power supply. A turn-on and turn-off sequence will be worked out in preparation for this test. This test will also be useful to exercise the control monitoring software and interface to the overall BTeV control and monitoring system. All voltage settings and read-back currents will be monitored and recorded in a database. Assembly of the HV and LV systems will be done in parallel. It is estimated to take 1 week calendar time. The test of both systems will take 2 weeks calendar time. Three physicists and a graduate student will be required.

13.14.11.3 Assemble and test slow control pulsing/monitoring system

The slow control system including pulsing and monitoring system will be installed and tested. The pulsing system is also a nice tool in the test of HPD and PMT electronics. The test of latter system will also provide test on the pulsing system. This monitoring system will be used for most of the tests later. The assembly and test of this system requires 2 physicists for 10 days.

13.14.11.4 Electronic test of front end devices

Before the installation, the front-end electronics are tested with stand-alone PCI based test stands. Once the whole system is connected we will test with a real readout chain for the DAQ in the experiment. The test is aimed at testing all HPD and PMT modules extensively in order to detect problems and fix them. The test will include following steps:

- Pedestal and noise calibration with no HV applied. We will read out the system with no signal sources but with a threshold scan. Most of the problems with front-end electronics show up with abnormal pedestal and noise pattern.
- Pedestal and noise calibration with HV applied. This test can tell us if the HV connection and grounding are proper so the pedestal and noise performance will not be affected much by the applied HV.
- Test with electronic pulse. The front-end electronics has the function to use an external signal pulse mimic the real signal. With this test we can determine if the

gain of certain channels is at the desired value. These tests require 2 physicists for 4 weeks to complete.

13.14.11.5 Test on light response of photo sensitive devices

The electronic test of front-end electronics does not include the functionality of the photon sensitive devices: HPD and PMT. In this test we use photons from light sources installed inside the RICH vessel to simulate the Cherenkov photons. An electronic pulser is used to drive the light source and trigger system. We read out the response of the HPD and PMT to the light source. Using point light sources, the response between neighboring channels should be quite uniform. This test will also be used to provide quick check on the system before running when the experiment starts to collect physics data. The test will take 4 weeks calendar time and 2 physicists are required.

13.14.11.6 Check alignment of HPD arrays and mirrors

The mirror tiles will be carefully aligned with respect to the supporting structure before the structure is mounted into the RICH vessel. The HPD arrays and mirror supporting structure are aligned with surveying. Once everything is installed, we rely on a collimated light system to check the alignment besides of using the data of isolated tracks. Collimated light sources will be mounted on the sides inside the RICH vessel. The positions and directions of the light sources are properly adjusted so that the reflected light from the mirror will be received by the HPD arrays on the opposite side. This test will take about 6 weeks calendar time.

13.14.11.7 Software requirements

Software is needed for test of the RICH detector. Offline data analysis software will be developed before the installation. The major components of the software that will be required for integration and testing are the database, a graphical user interface (GUI) for run control and DAQ monitoring, and online software for calibration and detector monitoring. The GUI and online software will be used to initialize the readout chain, set the operating parameters of the RICH detector (*e.g.*: HV, LV, threshold, running mode of the front end electronics), record events, display events, perform scan and so on. They will also be used to monitor the voltage, current, temperature, pressure inside the vessel, and alignment information of the detector. These will be extensively tested and debugged before the installation of the detector.

13.14.11.8 Time Required

We estimate that assembly and test of HV and LV systems will take about 3 weeks. Assembly and test of slow control pulsing/monitoring systems takes 2 weeks. Electronic calibration of front-end devices takes 4 weeks. To test light response of photosensitive devices takes 4 weeks. And checking the alignment takes 6 weeks. In total the tests at C0 take about 4 to 5 months.

13.14.12 Counting Room - DAQ and Trigger

13.14.12.1 Testing at C0 for the DAQ

Infrastructure tests

a) Utilities

Leak check cooling water systems.

b) Safety Systems

Test electrical safety.

c) Control/Monitoring System

Interface the detector control system to the detector specific control and monitoring system. Complete integration.

d) Timing/Clock System

Clocks will be needed to do a full readout test.

Stand-Alone DAQ Subsystem Testing

a) Mechanical

b) Electrical/Electronics

Check power supplies and network connections. Repeat internal test program developed previously using the Integration Test Facility.

c) Software

Repeat internal test program developed previously using the Integration Test Facility.

c) Personnel Required

d) Time Required

13.14.12.2 Testing at C0 for the Trigger System

Infrastructure tests

a) Utilities

Power system testing will occur very quickly with almost binary outcomes for voltage and power capability.

b) Safety Systems

Fire and chilled water safety system testing can be part of the building infrastructure testing. Both should be tested before or during trigger system installation also.

c) Control/Monitoring System

Control and Monitoring system connectivity and testing will be very flexible. The trigger system will be able to emulate the experiment run control system so there is no dependency on that operation. The internal Supervisor and Monitoring systems will be distributed applications that can be activated incrementally, adding resources as needed. The slow control connections will be activated as soon as possible so all testing will have temperature and airflow monitoring.

d)Timing/Clock System

There will be two connections to the timing/clock system, one is the pixel data preprocessor level and one at Global Level 1. Both connections will have emulators available for substitution when the experiment timing/clock system is unavailable. No other experiment systems require and/or depend on information from the trigger system.

Stand-Alone Subsystem Testing

There are four major subsections in the trigger system; 1) L1 muon trigger, 2) L1 pixel trigger, 3) Global Level 1 trigger, and 4) L2/3 trigger farm. Each subsystem will be designed to operate independently from the others for subsystem tests, generating simulated input data as needed and emulating upper level control functions. Each subsystem will have a granularity that allows a partial subsystem to demonstrate subsystem functionality with a reduced capacity. Stand-alone testing can occur within a partial subsystem or for any combination of partial subsystems. Stand-alone testing of the whole trigger system will first occur as a partial system test of partial subsystems. For the trigger system, this section applies both to the subsystem and system stand-alone testing.

a) Mechanical

Only rack space in the counting rooms is required to run a stand-alone system/subsystem at C0. This is assuming that there is enough mechanical hardware (e.g. false floor and false floor air vents) to give sufficient air flow for cooling purposes.

b) Electrical/Electronics

Only rack power and cooling is required to run a stand-alone system/subsystem at C0. Network connections will allow remote development on the trigger system. Data emulators will be designed into the data receivers of the trigger front-ends so that no pixel or muon detector hardware will be required for stand-alone testing.

c) Software

Before the trigger hardware is moved to C0, sufficient software development will be done to implement a functional trigger system. Software development will be an ongoing project.

d) Personnel Required

No personnel are required to run a stand-alone system/subsystem at C0 other than the trigger testing personnel. Remote and off-hours testing will be desired after initial trigger system/subsystem functionality is achieved.

e) Time Required

It is assumed that the installation of the trigger system hardware at C0 will follow the realization of a functional trigger vertical slice system test at FCC or UIUC. The time required to achieve a similar system at C0 should be accomplished approximately five weeks after the installation of the associated hardware. Expansion of the vertical slice will occur incrementally as hardware is installed and as input data is available. See below. In particular the software needed for testing the trigger subsystem and subsystem integration at C0 will be an ongoing project as needs arise, until full multiple subsystem testing is complete.

13.15 Organization

13.15.1 WBS 1.5 (Muon) System Installation, Integration Commisioning

13.15.1.1 Participants and Group Organization

Level 2 Subproject:

Level 2 Subproject Interim Manager& Institution: Will Johns, Vanderbilt

Level 2 Subproject Interim Manager& Institution: Paul Sheldon, Vanderbilt

Participants:

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Vanderbilt Univ.: Will Johns

Univ. of Illinois: Doris Kim

Univ. of Puerto Rico, Mayaguez: Zhong Chao Li

Univ. of Puerto Rico, Mayaguez: Angel Lopez

Univ. of Illinois: Mats Selen

Vanderbilt Univ.: Paul Sheldon

Univ. of Illinois: Michael Haney

Vanderbilt Univ.: Eric Vaandering

Vanderbilt Univ.: Med Webster

Univ. of Illinois: Jim Wiss

Working group	Name	Institute	
Plank Design and Construction	Paul Sheldon (*)	Vanderbilt	
	Aldo Acosta	Puerto Rico	Mayaguez
	Vaidas Simaitis	Illinois	
	Will Johns	Vanderbilt	
	Doris Kim	Illinois	
	Zhong Chao Li	Puerto Rico	Mayaguez
	Angel Lopez	Puerto Rico	Mayaguez
	Eric Vaandering	Vanderbilt	
	Med Webster	Vanderbilt	
	Jim Wiss	Illinois	
Readout electronics, HV, LV	Will Johns (*)	Vanderbilt	
Quad Design and Construction and Mechanical Support	Jim Wiss (*)	Illinois	
	Aldo Acosta	Puerto Rico	Mayaguez
	Chuck Brown	Fermilab	
	Vaidas Simaitis	Illinois	
	Michael Haney	Illinois	
	Will Johns	Vanderbilt	
	Angel Lopez	Puerto Rico	Mayaguez

13.15.2 WBS 1.10 System Installation, Integration Commisioning

13.15.2.1 Participants and Group Organization

Level 2 Subproject:

Level 2 Subproject Interim Manager& Institution: Chuck Brown, Fermilab

Level 2 Subproject Interim deputy manager: David Christian, Fermilab

Level 2 Subproject Interim deputy manager: John Anderson

Level 2 Subproject Interim deputy manager: Joe Howell

Participants:

Fermilab: (physicist) C. Brown, D. Christian, and P. Garbincius

Fermilab: (engineer) J. Howell, H. Cease, J. Anderson, E. Barsotti, E. Chi, M. Wong

Fermilab: (designer) J. Rauch

Fermilab: (technical specialist) L. Bagby

Working group	Name	Institute
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	J. Anderson, L. Bagby	
	P. Garbincius	
C0 Infrastructure	C. Brown	Fermilab
	J. Howell	
	D. Christian	
	J. Anderson, L. Bagby	
Transport, Assembly	C. Brown	Fermilab
	Members of WBS1.2 to 1.9	
Integrate, Test, Commission	D. Christian	Fermilab
	J. Anderson, L. Bagby	
	J. Howell	
	M. Wong	
	J. Rauch	